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SOUTHWESTERN PONDEROSA PINE FOREST STRUCTURE AND FIRE REGIME DISRUPTION DATE: RE-MEASUREMENT OF HISTORICAL PERMANENT FOREST PLOTS

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FINAL REPORT

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Executive Summary

Dense structural conditions found in contemporary ponderosa pine forests of the Southwest present striking contrast to the open canopied structure of pre-Euro-American settlement forests that occurred in the late 19th century. Alteration of indigenous disturbance regimes that included frequent, low-intensity fire, through livestock grazing and active fire suppression, encouraged coniferous tree population irruptions. Over the last ± 110 years, ponderosa forests have become dense with young trees, which has reduced vigor of older trees, inhibited understory plant communities, and caused accumulations of woody biomass and fuel. These structural changes coupled with fire exclusion have reduced biodiversity, altered biogeochemistry, increased mortality of old-growth trees, and fueled stand replacing wildfires. In this study we measured structural changes that have occurred over ~ 90 years on the oldest known southwestern forest plots (established from 1909 - 1913) in the ponderosa pine type. We relocated, mapped, and remeasured (1997 - 1999) 15 historical plots and compared these data with those recorded in historical ledgers. Results showed that subplot density had increased up to 33-fold since their establishment although density on two drier subplots in Arizona (COCS4A and COCS4B) had increased only slightly. The vast majority of trees on subplots were in smaller size classes (10.16 - 25.0 cm) in 1997 - 1999 and quadratic mean diameter had decreased on 12 of 15 subplots compared with historical data. On moister sites, subplots historically dominated by ponderosa pine showed increased occurrence of fire (frequent) intolerant species such as Douglas-fir.

Ecological degradation of ponderosa pine forests in the Southwest has prompted much interest in restoration to conditions more like those thought to exist prior to Euro-American settlement of the region. Important in the ecological restoration process is the determination of reference conditions. These are the structural, compositional, and functional characteristics of the ecosystem prior to degradation. They serve as reference points for developing restoration treatments and baselines against which restoration success can be measured. Determination of structural reference conditions can be approached by reconstructing stand histories (forest reconstruction). Reconstruction techniques used in southwestern ponderosa pine forests include field identification of presettlement structural evidence and growth and decomposition modeling. In this study, we analyzed reconstruction techniques by remeasuring plots established in Arizona and New Mexico from 1909 - 1913 and comparing our reconstruction estimates with historical data. Results of this analysis revealed several distinct sources of error: (1) After ~90 years, approximately 88 - 94% of the recorded trees were relocated and remeasured, but up to 33 trees per hectare (JEMS3A) were missed in the field due to obliteration by fire or decay; (2) sizes of trees living in 1909 were overestimated by an average of approximately 12% for Arizona subplots and 1.3% for New Mexico subplots; (3) snag and log decomposition models performed well for trees in Arizona (0.6% underestimate of historical DBH) but tended to overestimate time since death for trees in New Mexico (8.2% underestimate of historical DBH using the 25th percentile for decay rate); and (4) cutting dates of harvested trees were uncertain. The aggregate effect of these errors was to overestimate the number of trees occurring in 1909 - 1914. Our results suggest that these reconstruction techniques are robust, but the methodology presented here tended to overestimate tree size and forest density. Implications of these analyses are discussed.

Model adjustments based on reconstruction analyses allowed us to reconstruct forest structural conditions at the approximate date of fire exclusion (1876 - 1890). Subplot tree densities across all plots at fire exclusion ranged from 61 - 298 trees per hectare and averaged 136 trees per hectare. This contrasted with densities that ranged from 107 - 2009 trees per hectare in 1997 -1999 with an average of 855 trees per hectare. Large increases in number of smaller

diameter trees have shifted tree diameter distributions to negative exponential distributions. Ecological implications of these changes and future research directions are discussed.

Introduction

Southwestern ponderosa pine forest ecosystems have undergone striking and deleterious changes in forest structure and function as a result of elimination of the natural disturbance regime of frequent, low-intensity fires (Cooper 1960, Covington and Moore 1994a; 1994b). Because of unnaturally high tree densities, today's forest ecosystems in the Southwest are threatened by uncontrollable crown fires and other signs of ecosystem degradation. Overgrazing, logging disturbances, and fire suppression, have allowed southwestern forests to become dense with stressed, slow-growing trees (Covington and Moore 1994b). Forest floor fuel loadings have climbed to unsustainable levels, while the diverse herbaceous plant communities and the animals dependent upon them are being choked out of the ecosystem.

This study was designed to answer questions concerning the magnitude and extent of postsettlement structural changes in southwestern forests by remeasuring the oldest known permanent forest plots in the Southwest and by testing quantitative techniques for determining past forest structural conditions. We analyzed structural changes across a variety of ponderosa pine forests in Arizona and New Mexico. We were especially interested in changes since disruption (between 1870 - 1890, based upon most fire histories) of the natural, frequent, low-intensity fire regime. We reconstructed ponderosa pine forest structure around the time of Euro-American settlement (hereafter referred to as "presettlement" in this report) using a set of forest plots originally established by the U.S. Forest Service in the early 20th century across a number of forest types in the Southwest. By comparing the historical measurements (1909 - 1913) with contemporary remeasurement (1997 - 1999) of the same plots, we generated an index of forest change over that time period. We used these data to test and refine our reconstruction models and applied adjustments to reconstruct forest structure on these plots at the time of disruption of the natural frequent-fire disturbance regime (circa 1876-1890). Finally, we explored relationships among the variability in forest structure on these plots and site characteristics, fire history, and management history, seeking to generate hypotheses about larger-scale changes in southwestern forest structure, which can be tested in further studies.

Background:

Frequent, low-intensity fires recurred every 2 to 20 years in all except the most mesic southwestern forests prior to Anglo-American settlement (Weaver 1957, Biswell 1972, Kilgore 1981, Swetnam and Betancourt 1990, Covington et al. 1994, Swetnam and Baisan 1996). Fire played a key role in maintaining relatively open forests by controlling pine tree population irruptions and forest floor accumulations (Cooper 1960, Covington et al. 1994), and in maintaining a high level of nutrient availability (Covington and Sackett 1992). Ponderosa pine, a dominant forest and savanna species of the Southwest, evolved with fire, developing thick bark, insulated growing buds, and other adaptations to frequent fire regimes (Conkle and Critchfield 1988, McCune 1988, Barton 1993). Since the Pliocene, these forests have provided important evolutionary habitat for an exceptionally diverse biota, much of which appears to be dependent upon frequent fire. For the past 10-30 thousand years these forests have been vital resources for numerous human cultures, most recently (1850-present) for Anglo-American industrialization.

Soon after Anglo-American and Hispanic settlement of the Southwest region, heavy livestock grazing broke grass fuel continuity and active fire suppression eliminated the presettlement fire regime (Swetnam and Baisan 1996). Striking changes occurred in the absence of frequent fires: tree population irruptions (including conversion from fire-resistant species to fire-intolerant species), reduced tree vigor, increasing forest floor fuels, impoverishment of

herbaceous and other non-arboreal vegetation, shifts away from indigenous wildlife diversity, epidemic insect and disease outbreaks, severe stand-replacing crownfires, degradation of human habitat values (e.g., esthetics, biodiversity, watershed condition, and wood products) and threats to human life, health, and property (Williams et al. 1993, Kolb et al. 1994, Covington et al. 1994).

A variety of approaches have been used to quantify changes in southwestern forest structure and disturbance regime, including dendroecological reconstruction (Covington and Moore 1994b, Swetnam and Baisan 1996, Fulé et al. 1997), repeat photography (Veblen and Lorenz 1991, Covington and Moore 1994b), and comparison to historical accounts (Cooper 1960). One of the strongest potential methods, direct remeasurement of historical sampling plots, has been carried out in other settings. For example, Minnich et al. (1995) remeasured a set of plots established in southern California between 1929 and 1934, finding that forest density increased substantially and species composition changed away from frequent-fire adapted species, such as ponderosa and Jeffrey pines, toward true firs, during the 20th century. The change from presettlement conditions was probably greater because these plots were established after the disruption of frequent-fire regimes.

For this report, we studied a series of permanent forest plots that were established by the U.S. Forest Service in the Southwest Region between 1909 and 1913, under the direction of the pioneering researcher G.A. Pearson and Southwest Regional Forester T.S. Woolsey, Jr. We relocated and remeasured a subset of these plots. We used this data set to determine changes on the plots since their establishment and to validate models that reconstruct past forest structure. This allowed estimation of structural changes on the plots since the disruption of the natural frequent-fire regime. Finally, we explored this limited data set to generate hypotheses about large-scale ecosystem changes and potential ecological restoration treatments in southwestern forests.

Objectives

1. **Determine changes in forest structure (tree species, density, size, and age) on a subset of the permanent plots between the measurement date (1997 - 1999) and the plot establishment date (1909 - 1913).**

2. **Reconstruct forest structure for each plot at its establishment date (1909 - 1913) using dendrochronological techniques. Compare the reconstructed structure to the historical data to determine the precision and limitations of our reconstruction techniques and models.**

3. **Reconstruct forest structure at the date of initiation of fire exclusion (1876-1890), showing forest conditions at the time of disruption of the long-term, frequent-fire regime.**

The Woolsey Plots

We call the series of permanent sample plots established throughout the USFS Southwestern Region in the early 1900s "The Woolsey Plots" (Woolsey 1911, 1912; Pearson 1923, 1933, 1950) to credit T. S. Woolsey, Jr. for his work. In 1909, T.S. Woolsey, Jr., Assistant District Forester and Chief of the Office of Silviculture, District 3 (Southwestern District now Southwest Region 3), USFS; and G. A. Pearson, Director, Southwestern Forest and Range

Experimental Station (Flagstaff, AZ), USFS, drafted a set of instructions that would establish a network of permanent plots in the ponderosa pine forests of the Southwest. The need for such a series of plots on the National Forest was recognized since 1906 because little was known about western yellow pine (now ponderosa pine; *Pinus ponderosa* Laws.) and its management (Woolsey 1911, Woolsey 1912).

Two types of plots were established: "extensive" and "intensive". The "extensive" plots were very large (from 72 to 480 acres), while the "intensive" plots were smaller (from 2-14 acres on average); the "intensive" plots were often nested within the "extensive" plots (Pearson 1923, 1933, 1950). Pearson (1923, 1933, 1950) mentioned that the diameter of all trees was measured on both types of plots, although originally the trees on the "extensive" plots were not tagged. On "intensive" plots, trees of 10.16 cm (4.0 in) diameter at breast height (1.4 m) (DBH) and above were measured and mapped. Saplings, trees less than 10.16 cm DBH, were not mapped. But beginning in 1924 all trees on the "extensive" plots down to 9.14 cm (3.6 in) were also tagged and since 1939, the minimum limit for tagging and measuring was 19.30 cm (7.6 in). More detailed data were taken on the "intensive" plots (see below) and these plots were also stem-mapped (scale 1 inch = 1 chain). Commercial species mapped included ponderosa pine, Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco), white fir (Abies concolor *(Gord. and Glend.) Lindl. ex Hildebr.)*, and southwestern white pine (*Pinus strobifomis* Engelm.). Southwestern white pine was historically called Mexican white pine and there is some controversy regarding taxonomic separation of this species and limber pine (*Pinus flexilis* James). For this study, we use assumed 5-needle pines in New Mexico were southwestern white pine and those in Arizona were limber pine. Noncommercial tree species such as Gambel oak (*Quercus gambelii* Nutt.) and Utah juniper (*Juniperus osteosperma* (Torr.) Little) were noted on historical maps but were not tagged nor measured historically.

Between 1909 and 1915, seven "extensive" plots (combined area of 1,315 acres) and 51 "intensive" plots (combined area of 222 acres) were established within the ponderosa pine type of the National Forests in the Southwest (Woolsey 1911, Pearson 1923, 1933; Pearson 1950 says 2,000 acres of sampled plots; Ft. Valley Experimental Forest Archives). These plots were to be remeasured at 5-year intervals. Woolsey (1912) explained, "The general objective of these "intensive" reproduction plots is to secure accurate data along the following lines as a foundation for a system of management:

1. Actual increment in feet board measure or cubic feet.
2. Height and diameter growth of individual trees.
3. Death rate in different age classes.
4. Effect of the different degrees of cutting, methods of brush disposal, ground cover, soil, exposure, grazing, fires, insects, etc., upon seed[l]ing reproduction or the growth of individual trees.
5. Accurate photographic record to supplement paragraph 4."

The "intensive" plots were established in areas on which no timber sale had occurred within 5 years before the establishment of the plots. Woolsey and Pearson were interested in data from stands that were "cut-over" and how the trees that were left would react to that cutting. By today's standards, these "intensive" plots were large: "It is desirable that large plots from 10 to 15 acres be established where one general density, exposure, type, or slope would be included, otherwise areas of from 5 to 10 acres should be selected which embody a single feature. No plot of over 15 acres or under 5 acres should be established (Woolsey 1912)." Plot corners were permanently marked.

In addition to the tree characteristics of age class (black jack or yellow pine -- see discussion in Methods), height, diameter, and health of the tree, each tree was tagged and stem mapped. A portion or all of the following features appeared on the stem-mapped plots (Woolsey 1912):

1. Corners and witnesses.
2. All trees (of commercial species) > 4 inches at dbh (dob)
3. Seedlings over one foot high with their associated density symbols
4. Brush piles, burned and unburned
5. Downed trees
6. Seedling count strips or plots
7. Contours, roads, fire lines, drainages, etc.
8. Prevailing wind direction
9. Area of plot
10. Local compass variation
11. Stumps with corresponding diameters, outside bark, by species
12. Legend
13. Areas covered with brush or non-commercial species. In some instances where tree growth is dense this has to be made on a separate map.

Figure 1 is a scanned image of one "intensive" plot from the Coconino National Forest (Ft. Valley, Project Mc-2; Sample Plot S1-A) (see Appendix I for scanned images of historical maps for all remeasured Woolsey plots). This plot was originally logged in 1894, established (tree data collected) in 1909, and was stem-mapped in 1915. In addition to the data on standing trees and tree canopies, please note the distinction between categories of downed wood (felled, burned, broken, and windthrow), and reproduction categories (relative density, height, and location). Also note the small squares or subplots that are called "5 x 10 foot plot for seedling counts" (and "5 x 10 foot denuded"). On these 5 x 10 foot subplots all understory herbaceous and shrub species, as well as pine seedlings, were recorded and mapped (Pearson 1923). It is not known whether this understory information was recorded on all "intensive" plots throughout the Southwest or only those "intensive" plots established at Ft. Valley.

Detailed reports were filed on each plot and six typewritten copies were made. The original and one copy of the report was given to the Supervisor of the Forest, and two copies were given to the District Forester, District 3 (now called Regional Forester, Region 3). Two additional copies were made, but it was not specified where these records were filed. The original tracing linen maps and two blue prints were to be given to the District Forester, and two blue print copies were also given to the Supervisor of the Forest. "All original notes, maps, and records should be placed in the files of the Supervisor on which the plots are established. All records should be twice checked for errors (Woolsey 1912)."

A report was published from the initial data collected on a portion of these permanent plots by Woolsey in 1911 entitled, "Western yellow pine in Arizona and New Mexico." We presume that Woolsey's 1911 report uses only a portion of the data, since "intensive" plots were established between 1909 and 1915. In this 1911 report, Woolsey summarized much of what was known about the ecology and timber management of ponderosa pine at the time.

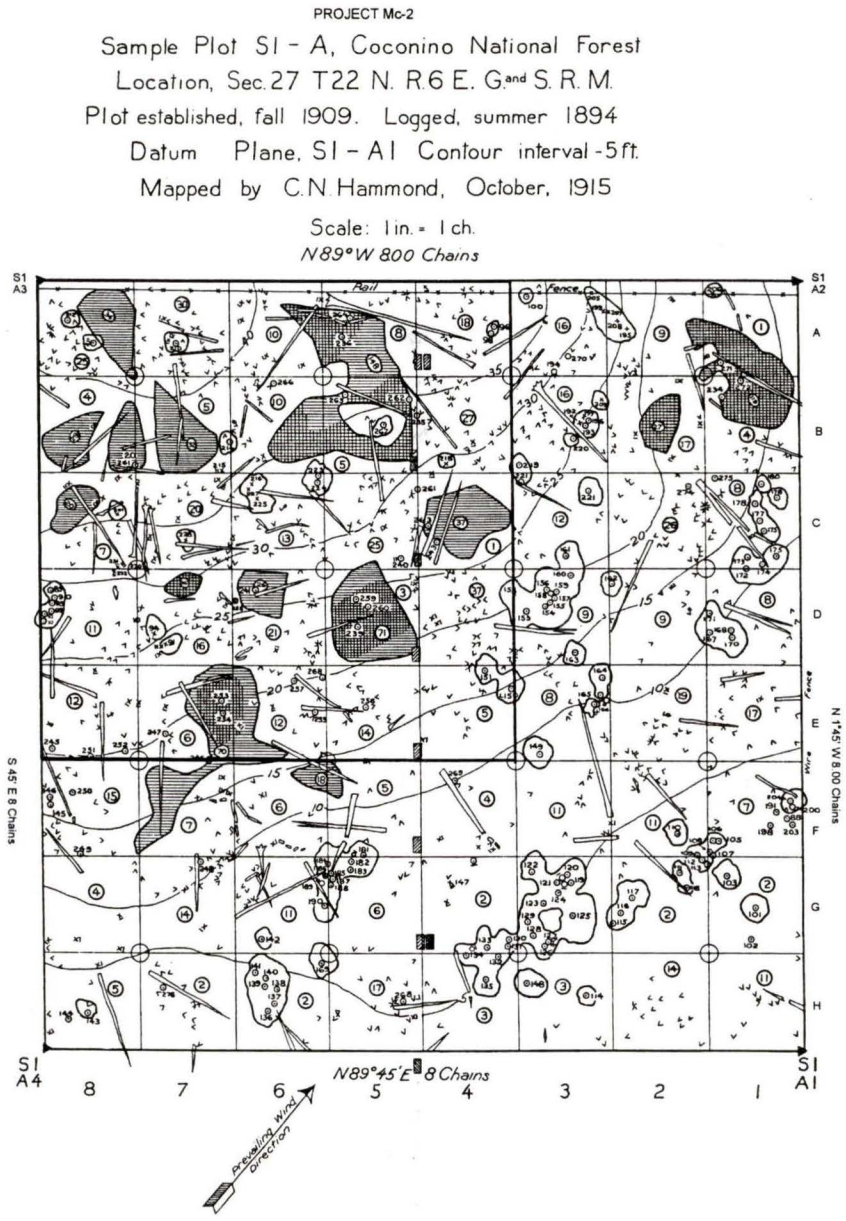
PROJECT Mc-2
Sample Plot S1 - A, Coconino National Forest
Location, Sec. 27 T22 N. R.6 E. G.and S. R. M.
Plot established, fall 1909. Logged, summer 1894
Datum Plane, S1 - A1 Contour interval - 5 ft.
Mapped by C.N. Hammond, October, 1915
Scale: 1 in. = 1 ch.
N89°W 800 Chains
S1 A3
S1 A2
S1 A4
S1 A1
N89°45'E 8 Chains
S 45 E 8 Chains
N 45 W 8.00 Chains
prevailing wind direction

Figure 1. Scan of original 1915 map for Woolsey plot COCS1A in Arizona. Outlined area indicates 100.6 x 100.6 m (5 x 5 chain) subplot.

As was mentioned earlier, these plots were to be remeasured at five-year intervals, however, a few were measured at 10 year intervals (Ft. Valley Experimental Station Archives). The date of last remeasurement for the ponderosa pine stands was sometime between 1934 and 1955, although one area (a portion of "S6", Gus Pearson Natural Area, Ft. Valley) was remeasured in 1976 (Ft. Valley Experimental Forest Archives, Avery et al. 1976). Pearson's (1933) article, "A twenty year record of changes in an Arizona pine forest" was the first (and perhaps only) published article that reports the remeasurement of two "intensive" plots located on the Ft. Valley Experimental Forest. In 1942, H. Krauch and R.H. Westveld relocated many of the original "intensive" plots, indicated the purpose of the plot, date of establishment, dates of remeasurement (if remeasured), and provided a map with the precise location of the original plot (Ft. Valley Experimental Forest Archives). In addition to relocation of the original "intensive" plots, Krauch and Westveld also relocated additional intensive-type plots that were established in the 1920s, 1930s, and 1940s. The results of this report focus on the remeasurement of a subset (n = 15) of the original 51 ponderosa pine "intensive" plots established between 1909 and 1913.

Methods

Study Area:

The study area included the network of permanent plots established by USFS Region 3 (Southwestern Region; Woolsey 1911, 1912) within the ponderosa pine type on the National Forests of Arizona and New Mexico. The National Forests of the Southwest mentioned in Woolsey's report (1911) or Pearson's (1923, 1950) monographs, and/or records of plot locations actually found in the Ft Valley Archives included: Apache, Carson, Cibola, Coconino, Gila, Kaibab, and Sante Fe. Records from the Prescott and Sitgreaves indicated that plots were established by Pearson and others in the ponderosa pine type in the 1920s and 1930s (Ft Valley Archives). These latter plots were smaller, often involved thinning experiments, and we are unsure of the exact information collected at this time. Records from the Lincoln National Forest show plots (n = 12) in the Douglas-fir (mixed-conifer) type, both cutover and virgin, near Cloudcroft, NM. An additional plot in the Douglas-fir type is described near Willow Creek, NM (Santa Fe National Forest). Eight plots were established on the Carson National Forest (near Angostura and La Junta, NM) in the Engelmann spruce (*Picea engelmanii* Parry ex Engelm.) type. No records from the Coronado or the Tonto were located; but they may in fact exist under another name, such as the National Forests in the Southwest as named in 1911. There was a grand total of 72 permanent plots in all. Although all of the plots and forest types are of interest, the focus of this study was remeasurement of the ponderosa pine plots. Table 1 lists all of the ponderosa pine plots established by Woolsey and Pearson and a brief description of plot establishment date, if the location or site maps were found, and if the plot was still intact between 1997 and 1999.

Subset of Plots:

The first four to six months of this study were used to gather the data, maps, and locate Woolsey's "intensive" plots in the field (plot corners remarked, GPS coordinates taken, and plot marked on a map). Only fifteen of the 51 original "intensive" plots were remeasured (Figure 2) because of time and cost constraints and the reality that some plots have been lost or destroyed. Ten plots were within the Coconino National Forest in northern Arizona and five plots were in New Mexico within the Cibola (2 plots), Gila (1 plot), and Santa Fe (2 plots) National Forests (see Appendix II for detailed descriptions of plots and their individual locations).

Table 1. List and details of all ponderosa pine plots established by Woolsey and Pearson

National Forest	Plot	Number of plots	Total Acres	Date of Origin	Information and data that exists and has been located					Relocated in Field (Date)	Condition of Plot	Township, Range and Section	Stand Type
					Location Map	Stem Map	Re-measure Data	Tree Data	Photos				
Apache (AZ)	S1	1	1.2	1910	√	√	√(1916)	√		not found **		Sec 7, T5N, R28E	mix conifer
	S2	1	2.0	1910	√	√	√(1916)	√		7/14/97	intact (no tags)	Sec 7, T5N, R28E	mix conifer
	S3	1	1.2	1910	√	√	√(1916)	√		***		Sec 32,T9N, R29E	mix conifer
Carson (NM)	Amola	1	2.75	1914	√	**	√(1944)	√	a few	6/22/97	intact	Sec 36, T23N, R12E	Pine
	Cienega	1	4.0	1914	√	**	√(1944)	√		6/22/97	intact	Sec 25, T23N, R12E	Pine
	Pueblo	1	4.2	1914	√	**	√(1944)	√		not found **		Sec 6, T22N, R16E	Pine
	La Junta	1	2.75	1914	√ √(description)	**	√(1944)	√		6/21/97	intact	Sec 20, T22N, R14E	Pine
	Angostura	6	10.0	1924	√	**	√(1945)	√		***		T21N, R13 and 14E	Engelmann
	Angostura	4	2.0	1922	√	**	√(1945)	√		***		T21N, R13 and 14E	Engelmann
Cibola (NM)	S1A	1	6.0	1910	√	√	√(1935)	√		7/08/97	mostly intact (roads)	Sec 11, T5S, R7W	Pine
	S1B	1	6.0	1910	√	√	√(1935)	√		7/09/97	intact	Sec 11, T5S, R7W	Pine
	S2A	1	14.4	1910	√	√	√(1935)	√		7/09/97	intact	Sec 9, T5S, R7W	Pine
Coconino (AZ)	S1A	1	6.4	1909	√	√	√(1934)	√	some	6/04/97	intact	Sec 27, T22N, R6E	Pine
	S1B	1	10.0	1909	√	√	√(1934)	√	**	7/31/97	intact	Sec 27, T22N, R6E	Pine
	S2A	1	7.0	1909	√	√	√(1934)	√	a few	8/4/97	intact (no tags)	Sec 25, T22N, R6E	Pine
	S2B	1	4.9	1909	√	√	√(1939)	√	a few	8/4/97	mostly intact (major Road N.	Sec 25, T22N, R6E	Pine
	S4A	1	8.0	1909	√ (description)	√	√(1934)	√	**	4/14/97	intact (no tags	Sec 22, T22N, R6E	Pine
	S4B	1	8.0	1909	√	√	√(1939)	√	**	***		Sec 22, T22N, R6E	Pine
	S5	29	52.0	1913	√	√	√(1943)	√	√	(6) 10/2-3/97	intact	Sec 19, T19N, R6E	Pine
	S6A	1	76	1925	√	*	√(1955)	√		***		Sec 22, T22N, R6E	Pine
	S6B	1	73.9	1940	√	*	√(1976)	√	a few	***		Sec 22, T22N, R6E	Pine
	S8	1	8.0	1926	√	*	√(1946)	√	a few	***		T20N, R7E	Pine
Gila (NM)	S1A	1	6.0	1912	√	√	√(1939)	√	a few	7/13/97	partly intact (road with cut bank)	Sec 4 T11S, R18W	Pine
	S2A	1	6.4	1912	√	√	√(1939)	√	a few	not found **	area has been burned, thinned	Sec 31, T15S, R13W	Pine
Kaibab (AZ)	S3A	1	12.0	1909	√	√	√(1954)	√	√	4/15/97	intact (thinned in recent past)	Sec 24, T22N, R5E	Pine
	S3B	1	12.0	1909	√	√	√(1954)	√	√	4/15/97	intact (thinned in recent past)	Sec 24, T22N,R5E	Pine
Lincoln (NM)	Cloudcroft	7	29.0	1925	general location	**	√(1945)	√		(1) 7/11/97	intact	Sec 16, T16S, R12E	Douglas-fir
	Cloudcroft	1	2.0	1927	general location	**	√(1945)	√		***		Sec 16, T16S, R12E	Douglas-fir
Prescott (AZ)	Copper Basin	3	1.8	1933	√	**	√(1948)	√		***		Sec 13, T13N, R2W	Pine
Santa Fe (NM)	Pecos S1A	1	6.0	1911	√	*	√(1934)	√		6/05/97	intact (no tags)	Sec 34, T17N, R14E	Pine
	Pecos S2A	1	6.0	1911	√	√	√(1934)	√		***		Sec 34, T17N, R14E	mix conifer
	Willow Cr.	1	4.0	1929	√	√	√(1934)	√		not found **		Sec 24,T18N, R12E	Douglas-fir
	Jemez S1A	1	6.0	1911	√	√	√(1934)	√		6/18/97	destroyed by development	Sec 8, T19N, R6E	Pine
	Jemez S2A	1	6.0	1911	√	√	√(1934)	√		6/13/97	mostly intact (power line - NW)	Sec 22,T19N, R6E	Pine
	Jemez S3A	1	6.0	1911	√	√	√(1934)	√		6/18/97	mostly intact (Road in N corner)	T19N, R5E	Pine

√ indicates the information or data that have been located (i.e., either from a Forest Service or National Archive Location).

* may not have ever existed (from looking at records of original data). ** an attempt was made to locate these plots or data, but as of 9/19/00, they have not been found.

*** not visited as of 9/19/00. Dates in the re-measure column indicate the last date data were collected

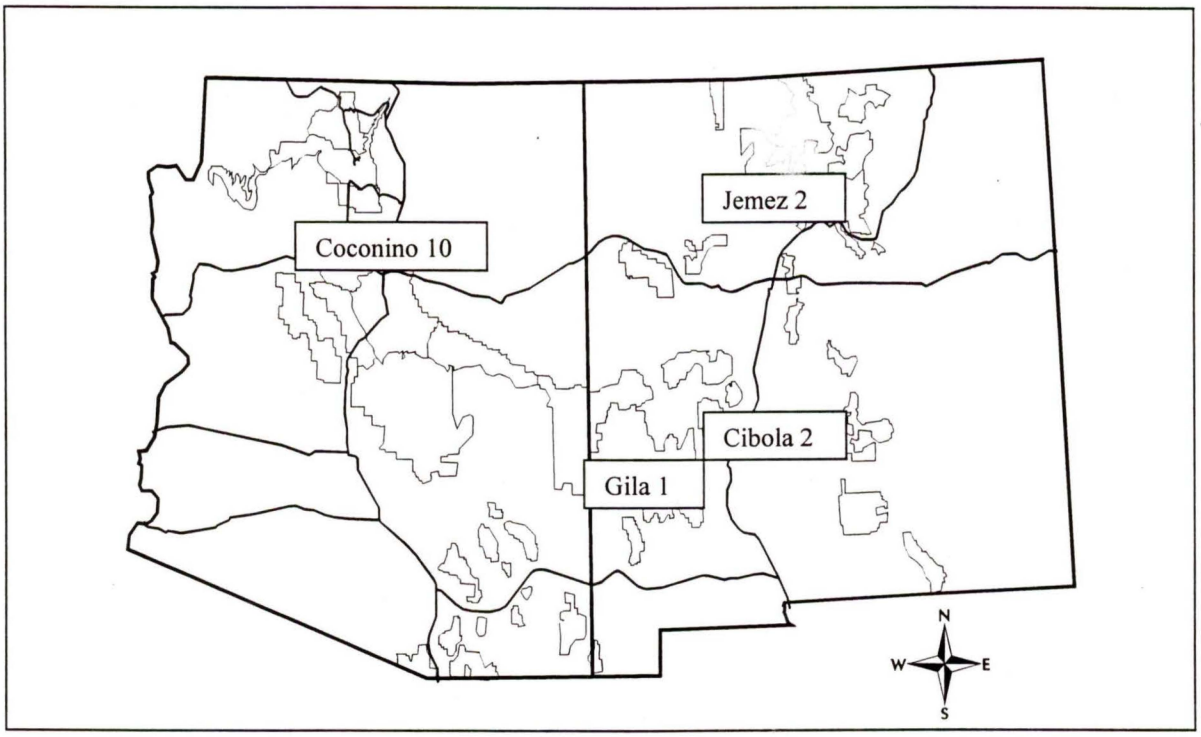

Figure 2. Map of general locations of Woolsey study sites and number of subplots in each area.

Field Measurements:

Data were collected and stem-mapped on a 100.5 x 100.5 m (5 chains x 5 chains) area of each original "intensive" plot. Most of the original plot corners and many of the interior, plot grid markers still existed, and aided in plot reestablishment. For consistency, the northwest corner of the original plot was selected as the origin for establishment of the remeasurement subplot. In cases of disturbance (e.g., roads, fire, development) to this plot corner, alternate origins were selected by progressing clockwise to successive plot corners until a minimally disturbed subplot was captured. Although no analysis was done to determine optimal subplot size, an area of 1.01 ha allowed us to (1) map and remeasure an extent as large as possible, within time and funding constraints (2) make interpretations on a scale of approximately one hectare, (3) ensure that presettlement tree groups (0.1 to 0.3 ha in size, White 1985) were captured in the data, and (4) reduce edge effect thereby minimizing problems of comparisons with the historically mapped data. Subplots were subdivided into grids of 20.1 x 20.1 m cells to facilitate mapping and measurement. All mapping was done with a Criterion400 survey laser unit.

Grid cells within subplots were thoroughly searched and all evidence of living or dead tree structures, either presently or at some past time reaching 1.4 m height, were numbered and tagged. Structures included live trees, snags, logs, stumps, and stump holes. Diameter (DBH), total height, condition class (1-9), and age class were recorded for all structures. Tree condition classes followed a classification system commonly used in ponderosa pine forests (Maser et al. 1979, Thomas et al. 1979). The nine classes were: 1) live, 2) fading, 3) recently dead, 4) loose bark snag, 5) clean snag, 6) snag broken above breast height (BH; 1.4 m), 7) snag broken below breast height (BH), 8) dead and down, and 9) cut stump.

In the field, age classifications were based on tree size and bark characteristics and then verified when possible in the laboratory. Tree ages were grouped in the field into three categories: presettlement, preplot, and postplot. Structures greater than 37.5 cm DBH, clearly yellow-barked, or dead, large, and highly decayed, were presumed to be greater than 100-years-old (White 1985) and classified as presettlement in age. Historically, Woolsey and Pearson classified trees into "blackjack" and "yellow pine" age classes. Blackjacks and yellow pine were described by Woolsey (1911) as follows: "Blackjack is merely the form which yellow pine assumes before it reaches the age of 125 or 150 years, during which period its bark is dark red-brown or blackish, with narrow furrows, in strong contrast to the lighter, widely furrowed bark of mature trees". Our presettlement classification corresponds to the yellow pine (mature trees > 150 years-old) described by Woolsey.

We classified trees as "preplot-aged" (i.e., established prior to historical plot measurement) if they did not meet presettlement classification criteria (e.g., did not have yellow bark) but were larger than a predetermined size. Preplot size was determined for individual subplots by measuring diameter and field aging a sample (10) of nearby trees. Ponderosa pine with bark appearing transitional in age between yellow barked and black barked trees were located just outside the subplot boundaries and cored at 40 cm. Ring counts were made and the results were compared with the plot establishment date. The average diameter of trees within 10 years of the plot establishment date was used as the preplot size cutoff. Live trees of this size or larger without yellow bark were classified as preplot-aged. In some cases, preplot size was not different than presettlement (37.5 cm at DBH) and classification was made based on bark characteristics. Our preplot class corresponds to Pearson's (1950) intermediate age class, which he discussed in a later publication but did not use during historical measurement of these plots.

Trees with black bark and smaller than the minimum presettlement and preplot diameters were classified as postplot. This class corresponds to Woolsey's (1911) blackjack age class. In our other studies, trees of this age class have been termed "postsettlement". Diameter at stump height (40 cm; DSH) and crown radius (average of two measurements) was measured for all presettlement and preplot ponderosa pine trees. For species other than ponderosa pine, DSH was measured on all trees. Increment cores were collected at 40 cm for all trees greater than 37.5 cm DBH and for oak and juniper species greater than 17 cm. Additionally, increment cores were collected and DSH and crown radius was measured for a 20% random sub-sample of live postplot (all species) trees. Increment cores were stored in paper straws until denrochronological analysis could be done in the laboratory. Our age classification scheme was designed to assure that detailed data, including increment cores, were collected for all trees that were historically measured or presettlement in age. It also allowed comparisons to made regarding changes in age structure on these plots since establishment.

Analyses:

Objective 1: *Determine changes in forest structure (tree species, density, size, and age) on a subset of the permanent plots between the measurement date (1997 - 1999) and the plot establishment date (1909 - 1913).* Comparisons were made between structural data collected at plot establishment (1909 - 1913) and those from our remeasurements (1997 - 1999). Statistical procedures were primarily descriptive. To compare past-present conditions on subplots, changes in tree density, species composition, basal area, and average size (quadratic mean diameter) were determined for trees ≥ 10.16 cm DBH. Diameter distributions at the two points in time were contrasted and compared graphically.

Objective 2: *Reconstruct forest structure for each plot at its establishment date (1909 - 1913) using dendrochronological techniques. Compare the reconstructed structure to the historical data to determine the precision and limitations of our reconstruction techniques and models.* A potential source of error in this reconstruction approach is missing presettlement-era woody material, which would lead to an underestimate of presettlement tree densities. Therefore, we used the historical maps of tree locations to evaluate our success in locating past forest structures (live or dead material) after 90 years. The original stem maps were used to reestablish subplot grid coordinates, and then they were not consulted again until subplot remeasurement was completed. When remeasurement was completed, we used the original maps to systematically visit the location of each historically mapped tree. Historical trees missed during remeasurement were recorded and notes were made regarding tree condition (e.g., live, dead and downed, no evidence).

The *reconstructed* forest structure at the date of plot establishment was compared with the *actual* historical measurements made 1909 - 1913 using the same characteristics (tree species, density, size, etc.). The degree of error in the reconstruction was assessed on a tree-by-tree basis to look for patterns of error in the techniques. Dendrochronological analysis of increment cores was done in the laboratory of the Ecological Restoration Institute at Northern Arizona University. Dendrochronological analysis included cross-dating increment cores (Fritts and Swetnam 1989, Stokes and Smiley 1968) against known annual ring patterns for Arizona and New Mexico (Graybill 1987), and measuring radial increments from the year prior to core collection (1997-1999) to the year of plot establishment (1909-1913). Radial increments to fire exclusion date were also measured and used later for Objective 3. Additional years to the tree center were estimated with a pith locator (concentric circles matched to the curvature and density of the inner

rings) for cores that missed the pith. The field determination of presettlement, preplot, or postplot tree status was confirmed or rejected using these actual age data..

Field measurements and increment core data were entered into a computerized stand reconstruction model (Covington et al. unpublished). A series of mathematical functions and routines were applied to field data in order to estimate tree diameters (DBH) and death dates for a particular point in time that was user-defined. Species-specific equations developed by Myers (1963) and Hann (1976) in the Southwest were used to estimate bark thickness and to predict DBH based on the inside-bark diameter of stumps. The year of death of presettlement snags and logs was estimated based on tree diameter and condition class (Rogers et al. 1984) of southwestern ponderosa pine as well as other species. Sizes of live trees, for which increment cores were collected, were reconstructed by subtracting twice the radial increment from field recorded tree diameters, projecting DBH from DSH measurements, and applying bark thickness equations. Separate functions were used for postplot and preplot/presettlement age classes as well as for other species such as Douglas-fir, white fir, Utah juniper, and piñon pine (*Pinus edulis* Engelm.). No equations were available to estimate growth of southwestern white pine so ponderosa pine functions were used as a rough approximation for this species. Sizes of trees for which no cores were collected, or for which core data was not usable, were estimated by applying "reverse" growth functions that we developed previously for individual species at various research sites in Arizona including Ft. Valley, Camp Navajo near Bellemont, and Grand Canyon National Park (n = 315 trees; $r^2 = 0.43$). A complete version of the reconstruction model can be found in Appendix III. The equation used for "reversing" ponderosa pine growth was as follows:

dbh_pr = (sqrt((dbh_x*dbh_x)-(((-.00034076 + (0.00003085*dbh_x))*(dtyr-exyr))/.00007854)

where: dbh_pr is the estimated DBH for the reconstructed tree;
dbh_x is the DBH outside bark measured in the field;
dtyr is the inventory (measurement) year or death year; and
exyr is the year to which the tree is reconstructed.

Dead trees were moved backward through decay classes (Maser et al. 1979, Thomas et al. 1979) (see below) until an estimated death date was reached; for years earlier in time than the death date, the reverse growth function was applied. We defined a cut date (see below) for field-measured stumps; trees were grown in reverse prior to this date. For our analyses, we compared subplot density and tree diameter output from the reconstruction model with data available from the historical ledgers. Since data in historical ledgers were restricted to trees ≥ 10.16 cm DBH, we limited our analysis of plot density to trees of this size.

To test reconstruction sensitivity for dead material and determine the model settings that reconstructed historical subplot structure most accurately, we varied tree cut date and decay rate parameters in the model. Snags and dead and downed tree structures were moved backward through decay classes at rates corresponding to the 25th, 50th, and 75th percentiles of movement found by Roger et al. (1984). We compared the diameters estimated in these iterations to the historical (1909 - 1913) data collected for these trees.

Similar sensitivity analysis was conducted for trees alive in 1909 - 1913 but cut sometime after plot establishment. Since the precise date that trees were cut was unknown to us, the following three cut dates were selected and modeled: (1) all trees cut the year following plot establishment date (e.g., cut date of 1910 for plots established in 1909), (2) trees cut in 1945, and (3) trees cut in 1980. These dates represented points within a range of time since plot

establishment and allowed us to evaluate model precision against general information regarding plot histories (e.g., relatively undisturbed until the late 1930s). Historical diameter of cut trees was compared to model estimates. Five combinations of decay rate and cut date settings were thus modeled for each subplot reconstructed to historical establishment dates. Size errors were calculated as follows: Error = ([Reconstructed DBH - Historical DBH]/ Historical DBH) * 100. Arizona and New Mexico subplots were grouped by state and averages for errors in size estimates were calculated for each group using real number values, as opposed to absolute values. We chose this approach since we were most interested in the net outcome for reconstructions.

Objective 3: *Reconstruct forest structure at the date of initiation of fire exclusion (1876-1890), showing forest conditions at the time of disruption of the long-term, frequent-fire regime.* Forest structure at the date of fire exclusion (1876-1890) was reconstructed by using model scenarios and adjustments indicated through completion of Objective 2. Comparisons were made between reconstructed presettlement subplots and conditions in 1997 - 1999.

Although Woolsey's "intensive" plots are a valuable resource for determining forest structure and decomposition rates during the early 1900s, and for assessing forest changes since that time, it must be remembered that these plots were established 30-45 years after selective logging had occurred and after disruption of the natural fire regime in the Southwest. Therefore, the "thinning" effect that fire would have had on seedlings (White 1985), the burning and breakdown of logs and forest floor materials, the rapid nutrient turnover rates, and the high understory production characteristic of the presettlement ecosystem would have been reduced or eliminated by 1909-1915. Thus, these "intensive" plots cannot be used alone and assumed to represent pre-Euro-American or pre-Hispanic forest stand structure and conditions. Fire histories exist throughout the Southwest (Swetnam and Dieterich 1985, Swetnam and Baisan 1996, Touchan et al. 1996, Fulé et al. 1997). A fire exclusion date of 1876 was selected for Arizona plots based on prior fire history research near the Woolsey plots (Dieterich and Swetnam 1984, Fulé et al. 1997). Fire exclusion date used for New Mexico plots was 1890 based on work by Touchan et al. (1996) (northern New Mexico) and Swetnam and Dieterich (1985) (central New Mexico). We also collected 10 - 15 cross-section samples of fire-scarred tree catfaces from live trees, stumps, or logs near each Woolsey plot to determine the date of fire exclusion for the individual plots. Fire scar cross-dating corroborated the selected fire exclusion dates obtained from the literature (exclusion dates of 1876 - 1884 for Arizona subplots and 1884 - 1904 for New Mexico subplots). Fire exclusion in Arizona Radial increments measured to fire exclusion dates were measured as described above in Objective 2 and used in model reconstructions.

To obtain a quantitative estimate of the forest stand structure and conditions at the time of Euro-American settlement necessitates that forest structures be reconstructed to the date of fire regime disruption (Swetnam and Baisan 1996, Fulé et al. 1997). Information resulting from completion of Objective 2, reconstruction to plot establishment date, was included as model adjustments for reconstructions to the time of fire regime disruption. Model scenarios (i.e., decay percentile and cut date parameters) that generated the most precise estimates of historical tree DBH were used and error rates associated with live, snags and dead and downed, and cut trees were applied to model outputs to adjust estimated diameters for the reconstructed subplots. Additionally, cut dates were set to the year immediately prior to plot establishment for stumps identified as presettlement-aged in the field but that had not been historically measured.

Due to the small number of trees within these various condition classes on individual plots, average error rates were calculated from results pooled for all subplots in Arizona or New Mexico. For example, the total number of historically measured trees still alive at remeasurement

was 277 for all Arizona subplots combined but ranged from 8 to 67 trees on individual subplots. Thus, the average error for adjusting live tree reconstructions was calculated from 277 trees rather than from 10 individual subplot averages. Arizona (10 subplots pooled) and New Mexico (5 subplots pooled) were considered separately for these calculations. Diameter distributions for subplots reconstructed to fire exclusion date were compared graphically with current distributions from our remeasurements.

Results

Structural Changes Since Plot Establishment:

Arizona Subplots: Density of trees (≥ 10.16 cm DBH) on subplots in northern Arizona ranged from 20 to 87 trees per hectare (TPH) at the time of original plot establishment (1909 -1913). This reflected some selective harvesting that occurred prior to 1909. Over the ± 90 years since plot establishment tree density on the subplots has increased. Figure 3 shows tree locations as recorded on the historical (1909) map of COCS1A compared with those plotted from our remeasurment (1997) (see Appendix IV for historical - remeasurement map comparisons of all subplots). An overall average increase of 12.9-fold was found when we compared the historical records to our remeasurement data (Table 2). Similar increases were found for subplot basal area (BA) and Reineke's Stand Density Index (SDI). One subplot (COCS4A) showed very little increase whereas the largest increase (COCS1B) was 32.7-fold. Changes in tree density were accompanied by general decreases in quadratic mean diameter (QMD) and mean tree basal area (Table 2). At plot establishment, 9 of 10 subplots had a QMD greater than 35 cm. At remeasurement, only three of the 10 plots had a QMD greater than 35 cm. Subplots COCS4A and COCS4B showed increases in QMD (Table 2).

Expectedly, diameter distributions on the subplots have shifted from larger to smaller size classes over the 90-year period. Figure 4 shows a comparison of subplot COCS1A establishment and remeasurement diameter distributions. This shift was representative of structural changes on most plots (see Appendix V for diameter distribution comparisons for all subplots). Most trees plot at establishment were in the younger age classes, recorded by Pearson and others as blackjack-aged versus older, yellow pine-aged ponderosa pine (Table3). Although there were greater numbers of younger trees on subplots, BA was distributed more or less evenly between blackjack and yellow pine-aged trees (Table 4). Using this age classification, younger trees continued to dominate most subplots at remeasurement due to heavy regeneration over the 90-year period (Table 3). The proportion of subplot BA comprised by yellow pine-aged trees has generally decreased (Table 4).

Species composition on Arizona subplots at remeasurement (1997 -1999) did not differ greatly from those recorded at plot establishment (Table 3). All plots were dominated by ponderosa pine and there has been no recruitment of more shade tolerant species into these subplots over the 90-year period. It should be noted that these analyses were restricted to species originally measured, thus species such as Gambel oak and Utah juniper that we recorded on the subplots were not included in these tables. However, all species were examined in presettlement reconstructions below.

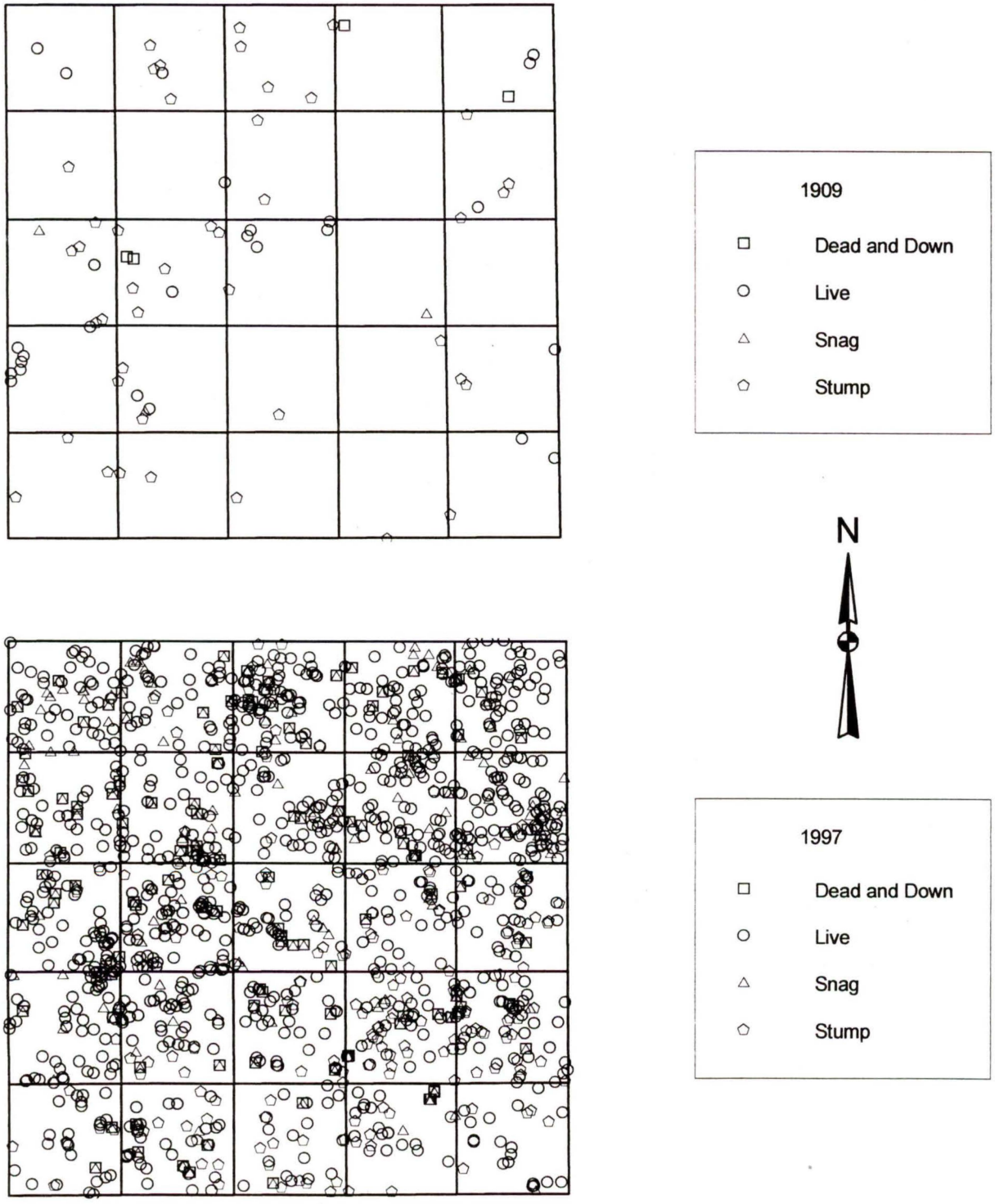

Figure 3. Maps of tree (greater than or equal to 10.16 cm DBH) locations on COCS1A at subplot establishment (1909) and remeasurement (1997) dates. Diameters were recorded only for live trees at plot establishment date (1909) and not for dead and downded, snags, and stumps.

Table 2. Size and density summaries for live trees ≥ 10.16 cm (4 in) DBH on Woolsey subplots in Arizona. Summaries for 1998 include only species that were historically measured. Values at time of plot establishment (1909-1913) and remeasurement (1997-1999).

Subplot	Year	Number of Trees	Subplot BA (m^2/plot[1])	Mean BA (m^2/tree)	QMD (cm)	SDI*
COCS1A	1909	26	3.0	0.12	38.5	50
	1997	661	42.5	0.06	28.6	790
COCS1B	1909	25	5.8	0.23	54.5	84
	1998	817	28.6	0.03	21.1	601
COCS2A	1909	82	13.9	0.17	46.8	216
	1998	575	33.4	0.06	27.2	634
COCS2B	1909	72	11.3	0.16	44.8	177
	1998	702	45.7	0.06	28.8	848
COCS3A**	1909	47	5.3	0.11	37.9	88
	1998	658	36.5	0.05	26.6	699
COCS3B**	1909	58	8.7	0.15	43.7	137
	1999	285	28.3	0.10	35.6	484
COCS4A	1909	87	8.0	0.09	34.2	137
	1999	91	15.2	0.17	46.2	235
COCS4B	1909	61	7.0	0.11	38.3	116
	1999	99	12.5	0.13	40.1	203
COCS5A2	1913	20	3.1	0.15	44.4	48
	1999	548	30.3	0.05	26.5	579
COCS5B3	1913	83	10.54	0.13	40.2	171
	1999	455	27.0	0.06	27.5	511

[1]Approximately equal to one hectare (100.1 x 100.1 m)

* Reineke's Stand Density Index (SDI metric) = $TPH*(QMD/25.4)^{1.605}$

** Plots were thinned from below since 1934 as part of silvicultural experiments, Ft. Valley.

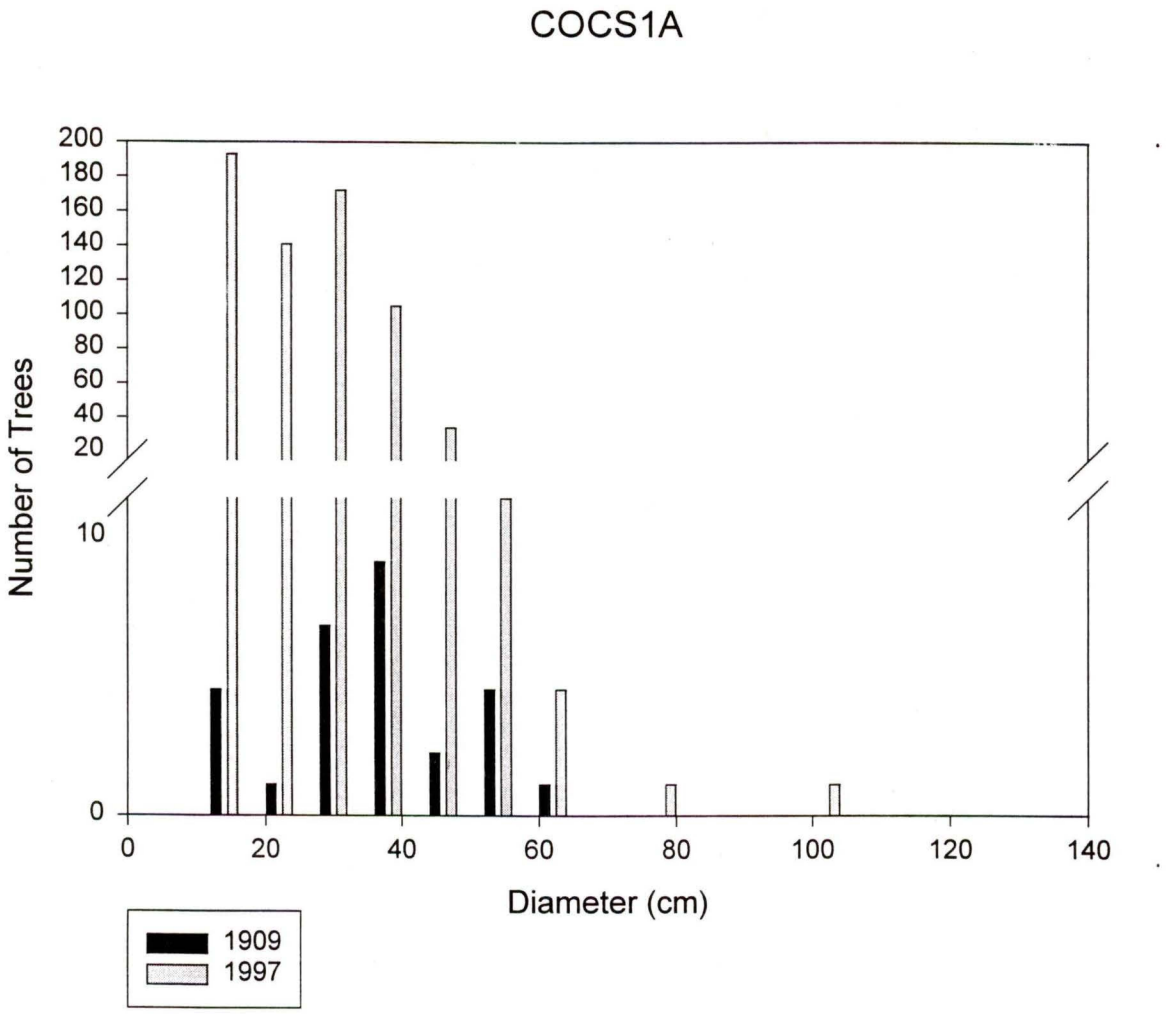

Figure 4. Diameter distributions for trees ≥ 10.16 cm (4 in) DBH on Arizona subplot COCS1A in 1909 and 1997.

Table 3. Proportion of trees by species for trees ≥ 10.16 cm (4 in) DBH on Woolsey subplots in Arizona (BJ = blackjack, YP = yellow pine age groups for ponderosa pine). Percentages at time of plot establishment (1909-1913) and at remeasurement (1997-1999).

Subplot	Year	Ponderosa pine BJ (%)	Ponderosa pine YP (%)	Douglas-fir (%)	Southwestern white pine (%)	White fir (%)	Trees per Subplot[1]
COCS1A	1909	62	38	0	0	0	26
	1997	84	16	0	0	0	661
COCS1B	1909	36	64	0	0	0	25
	1998	96	4	0	0	0	817
COCS2A	1909	54.0	46	0	0	0	82
	1998	87	12	+	+	0	575
COCS2B	1909	62.5	37.5	0	0	0	72
	1998	87	13	0	0	0	702
COCS3A	1909	96	4	0	0	0	47
	1998	89	11	0	0	0	658
COCS3B	1909	100	0	0	0	0	58
	1999	87	13	0	0	0	285
COCS4A	1909	93	7	0	0	0	87
	1999	55	45	0	0	0	91
COCS4B	1909	100	0	0	0	0	61
	1999	75	25	0	0	0	99
COCS5A2	1913	70	30	0	0	0	20
	1999	98	2	0	0	0	548
COCS5B3	1913	80	20	0	0	0	83
	1999	87	13	0	0	0	455

[1]Approximately equal to one hectare (100.1 x 100.1 m)
+ Less than 1%

Table 4. Proportion of basal area (BA) by species for trees ≥ 10.16 cm (4 in) DBH on Woolsey subplots in Arizona (BJ = blackjack, YP = yellow pine age groups for ponderosa pine). Percentages at time of plot establishment (1909-1913) and at remeasurement (1997-1999).

Subplot	Year	Ponderosa pine BJ (%)	Ponderosa pine YP (%)	Douglas-fir (%)	Southwestern white pine (%)	White fir (%)	Total BA (m^2/plot[1])
COCS1A	1909	44	56	0	0	0	3.0
	1997	63	37	0	0	0	42.5
COCS1B	1909	19.5	80.5	0	0	0	8.4
	1998	79	21	0	0	0	28.5
COCS2A	1909	22	78	0	0	0	13.8
	1998	65	34	+	+	0	33.4
COCS2B	1909	35	65	0	0	0	11.3
	1998	56	44	0	0	0	45.7
COCS3A	1909	85	15	0	0	0	5.3
	1998	69	31	0	0	0	36.5
COCS3B	1909	100	0	0	0	0	8.7
	1999	64	36	0	0	0	28.3
COCS4A	1909	81	19	0	0	0	8.0
	1999	35	65	0	0	0	15.2
COCS4B	1909	100	0	0	0	0	7.0
	1999	56	44	0	0	0	12.5
COCS5A2	1913	18	82	0	0	0	3.1
	1999	91	9	0	0	0	30.3
COCS5B3	1913	58	42	0	0	0	10.5
	1999	44	56	0	0	0	27.0

[1]Approximately equal to one hectare (100.1 x 100.1 m)
+ Less than 1%

New Mexico Subplots: Trends on New Mexico subplots were similar to those found in Arizona, however, magnitudes were not as great (Table 5). At plot establishment date, subplot (1 ha) tree density ranged from 89 to 222, somewhat denser than the Arizona subplots. Figure 5 shows tree locations as recorded on the historical (1910) map of CIBS1A compared with those plotted from our remeasurment (1998) (see Appendix IV for historical - remeasurement map comparisons of all subplots). All plots showed an increase in tree density, ranging from 2.1- to 11.9-fold. Subplot BA and Reineke's SDI increased from 1.5- to 7.1-fold and 1.6- to 5.3-fold, respectively. Quadratic mean diameter of trees on subplots at establishment was noticeably smaller than on Arizona subplots, ranging from 27.5 to 35.7 cm. Decreases in QMD were found at remeasurement for all New Mexico subplots except JEMS3A for which QMD essentially did not change.

On New Mexico subplots, increases in all size classes were found when diameter distributions from plot establishment and remeasurement periods were compared. The largest increases occurred in the smallest (10.1 - 15.0 cm and 15.1 - 25.0 cm) size classes. Figure 6 shows a comparison of diameter distributions from subplot CIBS1A that represents changes observed on most New Mexico subplots (see Appendix IV for diameter distribution comparisons for all subplots). Blackjack-aged trees dominated all New Mexico subplots at plot establishment date (Table 6). However, on subplot JEMS2A, yellow pine-aged trees comprised the majority of the BA (Table 7). After 90 years, general patterns found at plot establishment had persisted. In contrast to Arizona subplots, yellow pine-aged trees generally comprised an increased proportion of BA on most subplots at remeasurement, but not more than that of blackjacked-aged trees.

Species composition on subplots of nearly pure ponderosa did not change significantly over the 90-year period. However, the proportion of Douglas-fir increased on subplots where this species was present in both number and BA (Tables 6 and 7). Southwestern white pine increased on subplot GILAS1A but decreased on CIBS1A (Tables 6 and 7). White fir, which was not present ($\geq$ 10.16 cm DBH) in 1910 - 1912, was present in small amounts in 1998.

Reconstruction Analysis:

Arizona Subplots: Nearly all the trees mapped and recorded in 1909 through 1913 were relocated on the ten Arizona subplots (Table 8). Historical trees were found in all condition classes from highly decomposed remnant structures to live trees still bearing 90-year-old tags. The number of trees missed ranged from 0 to 9 and the overall error rate was 5.7 %. Frequently, missed trees were highly decomposed and little evidence was observable (e.g., stump holes). Most (78%) of the missed trees were < 30.0 cm DBH in 1909 - 1913. Additionally, 66% had died $\geq$ 60 years prior to our remeasurements in 1997 - 1999 (Table 9). A high rate of identification of historical trees was possible although dense stand conditions existed at the time of subplot remeasurement (1997 - 1999); there was an average of 1,379 total tree structures across the 10 subplots. A significant relationship was observed between the number of trees missed and the number that were historically measured when Arizona and New Mexico plots were pooled (see ***Reconstruction Analysis:*** **New Mexico Plots;** Figure 8).

Diameter reconstruction of historical trees that were still alive at remeasurement overestimated DBH by an average of 11.9 % and ranged from 5.6 to 22.1 % (Table 10). We found a slight trend of increased error for smaller trees (Figure 7). There were no subplots on which tree diameter was underestimated. Unexpectedly large errors (> 60 %) resulted for diameter reconstruction of unusually large or small trees for which increment data was unavailable (rotten tree centers, incomplete cores, etc).

Table 5. Size and density summaries for live trees ≥ 10.16 cm (4 in) DBH on Woolsey subplots in New Mexico. Summaries for 1998 include only species that were historically measured for comparison. Values at time of plot establishment (1910-1912) and remeasurement (1997-1999).

Subplot	Year	Number of Trees	Subplot BA (m^2/plot[1])	Mean BA (m^2/tree)	QMD (cm)	SDI*
CIBS1A	1910	105	6.2	0.06	27.5	118
	1998	597	18.5	0.03	19.9	397
CIBS2A	1910	125	8.9	0.07	30.0	161
	1998	259	13.5	0.05	25.8	256
GILAS1A**	1912	59	4.9	0.08	32.4	119
	1998	701	32.1	0.04	24.1	637
JEMS2A	1911	89	8.9	0.10	35.7	152
	1998	349	24.6	0.07	29.9	448
JEMS3A	1911	222	14.2	0.07	29.0	288
	1998	470	31.8	0.07	29.3	584

[1]Approximately equal to one hectare (100.1 x 100.1 m)

* Reineke's Stand Density Index (SDI metric) = $TPH*(QMD/25.4)^{1.605}$

** Subplot size = 0.73 ha (remaining measurable portion of the plot)

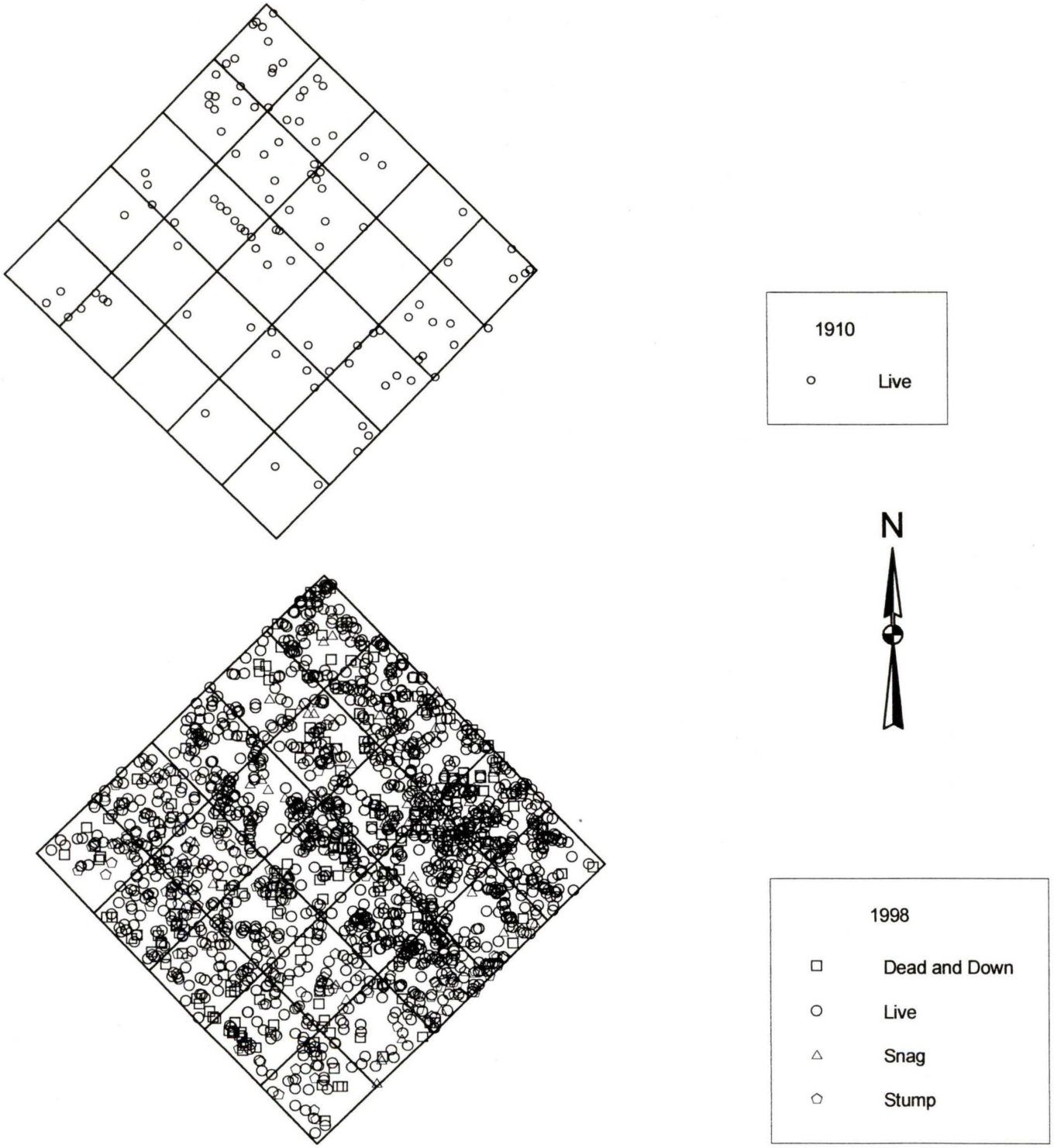

Figure 5. Maps of tree (greater than or equal to 10.16 cm DBH) locations on CIBS1A at subplot establishment (1910) and remeasurement (1998) dates. Tree locations were recorded only for live trees at plot establishment date (1910) and not for dead and downed, snags, and stumps.

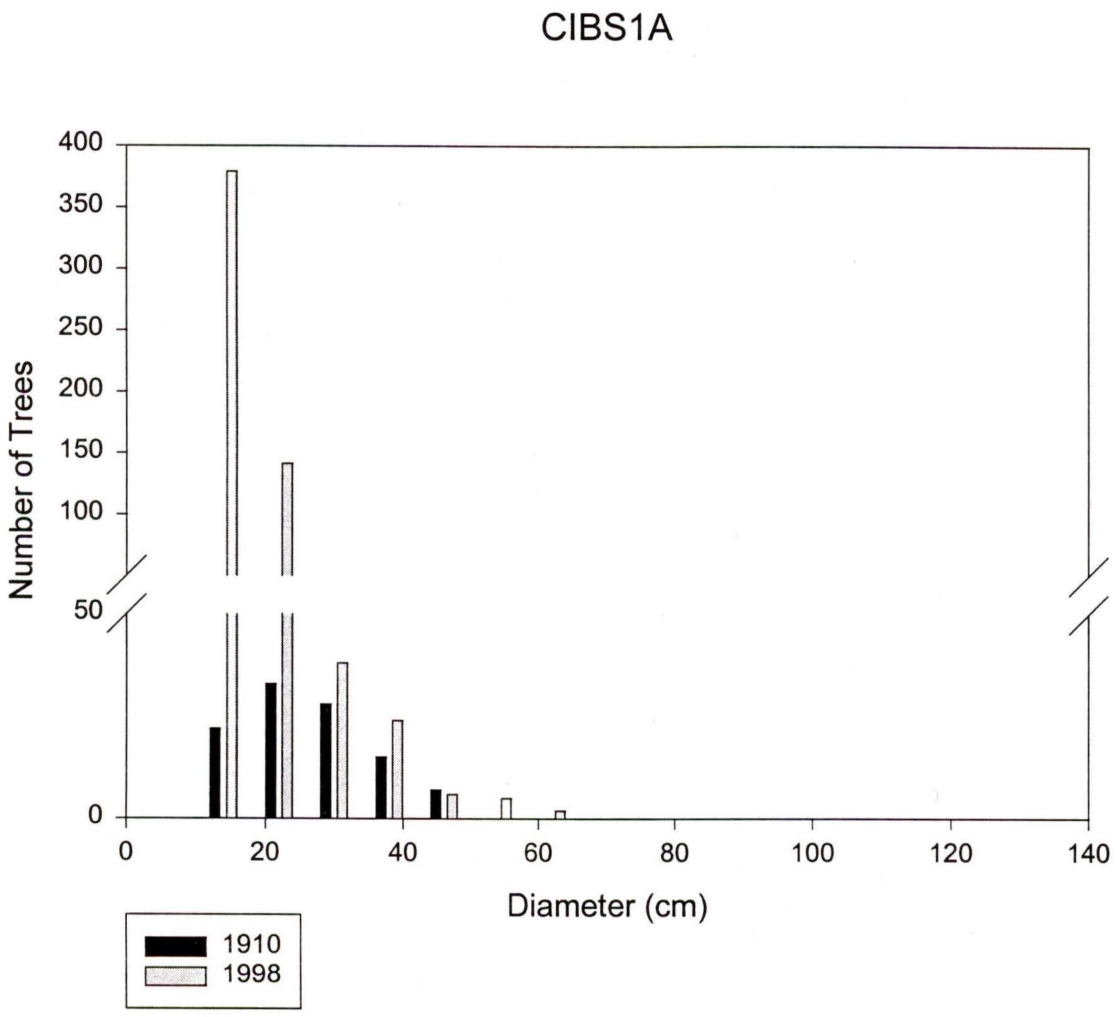

Figure 6. Diameter distributions for trees ≥ 10.16 cm (4 in) DBH on New Mexico subplot CIBS1A in 1910 and 1998.

Table 6. Proportion of trees by species for trees ≥ 10.16 cm (4 in) DBH on Woolsey subplots in New Mexico (BJ = blackjack, YP = yellow pine age groups for ponderosa pine). Percentages at time of plot establishment (1910-1912) and at remeasurement (1998).

Subplot	Year	Ponderosa pine BJ (%)	Ponderosa pine YP (%)	Douglas-fir (%)	Southwestern white pine (%)	White fir (%)	Trees on Subplot
CIBS1A	1910	60.0	17.1	5.7	17.1	0	105
	1998	66.2	9.6	21.3	3.0	0	597
CIBS2A	1910	85.0	15.0	0	0	0	125
	1998	86.1	13.5	0	+	0	259
GILAS1A*	1912	72.9	8.5	16.9	1.7	0	59
	1998	33.7	4.6	47.5	13.7	+	701
JEMS2A	1911	64.0	35.9	0	0	0	89
	1998	81.4	18.3	+	0	0	349
JEMS3A	1911	96.7	1.9	1.4	0	0	222
	1998	70.8	22.0	4.2	+	2.5	470

+ Less than 1%

* Subplot size = 0.73 ha

Table 7. Proportion of basal area (BA) by species for trees ≥ 10.16 cm (4 in) DBH on Woolsey subplots in New Mexico (BJ = blackjack, YP = yellow pine age groups for ponderosa pine). Percentages are for time of plot establishment (1910 - 1912) and remeasurement (1998).

Subplot	Year	Ponderosa pine BJ (%)	Ponderosa pine YP (%)	Douglas-fir (%)	Southwestern white pine (%)	White fir (%)	Total BA (m^2/subplot)
CIBS1A	1910	45.9	24.6	11.4	18.1	0	6.2
	1998	47.6	28.6	20	3.8	0	18.5
CIBS2A	1910	73.0	27.0	0	0	0	8.9
	1998	59.9	40.0	0	+	0	13.5
GILAS1A*	1912	45.8	22.8	30.6	+	0	4.9
	1998	34.9	16.5	37.1	10.3	1.0	34.7
JEMS2A	1911	35.9	64.0	0	0	0	8.9
	1998	54.7	45.1	+	0	0	24.6
JEMS3A	1911	92.0	5.6	2.0	0	0	14.2
	1998	37.9	55.4	4.0	+	2.5	31.8

* Subplot size = 0.73 ha
+ Less than 1%

Table 8. Number of live trees (≥ 10.16 cm DBH) on Woolsey subplots in Arizona at plot establishment (1909-1913) and the number missed during remeasurement (1997-1999).

Subplot	Number of Trees on Subplot	Number of Trees Missed	Error %
COCS1A	26	1	3.8
COCS1B	25	2	8.0
COCS2A	82	5	6.1
COCS2B	72	2	2.8
COCS3A	47	9	19.1
COCS3B	58	2	3.4
COCS4A	87	8	9.2
COCS4B	61	0	0.0
COCS5A2	20	1	5.0
COCS5B3	83	2	1.2
Weighted Average			***5.7***

Table 9. Characteristics of historically (1909 - 1913) measured trees that were missed in the field during remeasurement (1997 - 1999) on Arizona Woolsey subplots. All trees were ponderosa pine, historically recorded in blackjack (BJ) or yellow pine (YP) age classes. Historical condition was recorded on ledgers dating from 1909 - 1939.

Subplot	Age Class	Historical Diameter (cm)	Historical Condition
COCS1A	BJ	17	dying 1934
COCS1B	BJ/YP	40.6	unhealthy 1919 - lightning
COCS1B	BJ	25.4	forked (stump w/ 2 centers 1998)
COCS2A	YP	64.8	unhealthy 1914 - burned at base
COCS2A	YP	64.0	dead 1929
COCS2A	BJ	24.6	unhealthy 1914 - mistletoe
COCS2A	BJ	33.5	unhealthy 1914 - mistletoe
COCS2A	BJ	23.4	dead 1934
COCS2B	BJ	10.7	porcupine top 1924
COCS2B	YP	63.2	dead 1919
COCS3A	BJ	22.9	dead 1939
COCS3A	BJ	20.8	dead 1919
COCS3A	BJ	22.1	dead 1939
COCS3A	BJ	34.5	unhealthy 1919 - porcupine damage
COCS3A	BJ	22.4	dead 1924
COCS3A	BJ	20.3	dead 1919
COCS3A	BJ	25.1	dead 1919
COCS3A	BJ	16.5	dead 1919
COCS3A	BJ	18.0	dead 1914
COCS3B	BJ	30.0	dead 1939
COCS3B	BJ	31.5	dead 1939
COCS4A	BJ	20.6	suppressed, unhealthy 1919
COCS4A	BJ	13.2	forked w/1337
COCS4A	BJ	22.9	cut 1924
COCS4A	BJ	14.5	cut 1924
COCS4A	BJ	23.1	cut 1924
COCS4A	BJ	21.1	dead 1919
COCS4A	BJ	13.2	dead 1919
COCS4A	BJ	22.9	forked w/1364
COCS5A2	BJ	18.5	dead 1918
COCS5B3	BJ	23.1	dead 1918
COCS5B3	BJ	28.4	dead 1933

Table 10. Errors (%) and standard deviation (SD) for reconstruction estimates of historical tree diameters (≥ 10.16 cm DBH) and number (n) of live trees in analysis for Woolsey subplots in Arizona.

Subplot	Error (%)	SD	n
COCS1A	9.2	28.3	17
COCS1B	6.4	10.7	9
COCS2A	6.6	37.7	29
COCS2B	10.5	21.4	44
COCS3A	19.3	18.0	8
COCS3B	13.3	18.5	29
COCS4A	22.1	35.6	37
COCS4B	5.6	23.7	23
COCS5A2	20.9	20.4	14
COCS5B3	9.7	16.6	67
Average[a]	***11.9***		

[a]Average weighted by sample size (n).

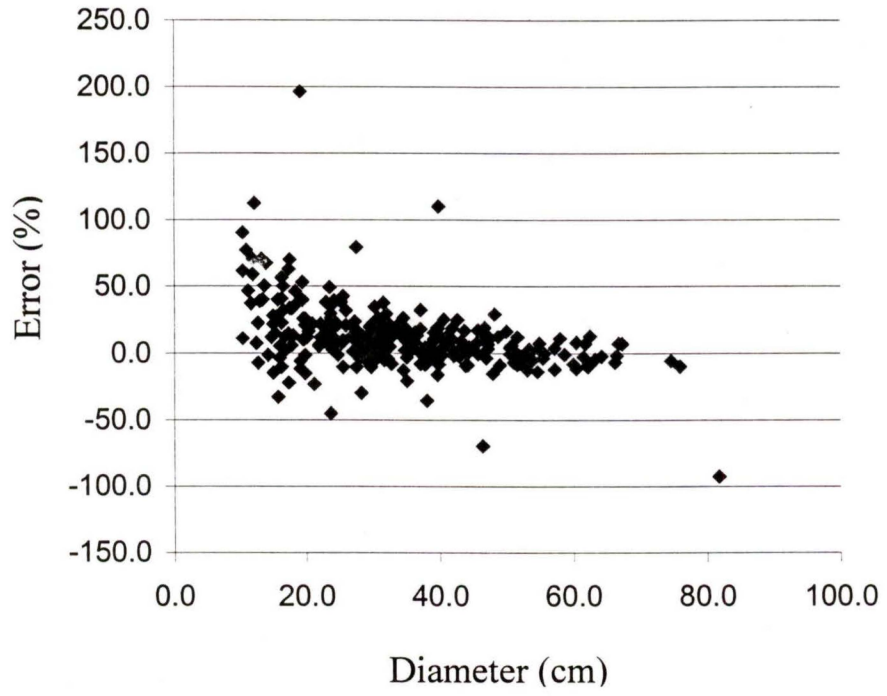

Figure 7. Relationship of error (%) and diameter for DBH reconstruction of historically measured live trees at remeasurement (1997 - 1999) on Arizona subplots. Diameter is value historically (1909 - 1913) recorded for these trees.

Error for diameter reconstruction of trees alive in 1909 -1913 but were snags and dead and downed at remeasurement averaged -0.6% and ranged from -6.7 to 6 9% (Table 11). Sensitivity analysis showed that dead and downed were most accurately reconstructed when moved through decay classes at the 50th percentile rate. Varying decay rate to the 25th percentile slowed movement through decay classes, resulting in earlier estimated death dates and a greater overestimate of historical diameters. Conversely, decay rate set to the 75th percentile sped movement through decay classes, resulting in later estimated death dates and an underestimate of historical diameters. Thus, varying decomposition rates altered size estimates by approximately ±6.5%. Due to limited number of historically measured trees that were dead and downed at remeasurement, the overall average was heavily influenced by subplot COCS2A.

Diameter reconstruction of historical trees that had been cut since original plot establishment (1909 - 1913) was most accurate when the cut date in the model was set to 1980 (Table 12). This was true for every subplot except COCS4A for which diameter estimates were most accurate when the cut date was set to 1945. Averaged over all subplots, diameter reconstruction of cut trees overestimated DBH at plot establishment by 11.4% using a 1980 cut date.

Reconstructed subplot densities were higher than those recorded on historical maps (Table 13). Total number of reconstructed trees on subplots represented the sum of: (1) historically measured trees, (2) trees historically existing on subplots yet too small (< 10.16 cm) at original plot establishment to be mapped, (3) trees that had died or had been cut prior to plot establishment, and (4) large live trees for which no increment core data existed. Thus, as DBH was overestimated in reconstructions, trees not historically measured due to their small size, were included in subplot reconstruction totals (i.e., estimated to be ≥ 10.16 cm DBH). To more clearly evaluate reconstructed plot densities we subtracted large stumps that were not historically recorded. We presumed these to represent trees cut prior to plot establishment. We also subtract trees for which increment core center dates were less than plot establishment dates. These trees we presumed were too small to be historically measured. Subtraction resulted in plot density overestimates of 10 - 51 trees per subplot (Table 13). Trees comprising the overestimates were snags and dead and downed trees for which death dates were inaccurately estimated and large live trees for which no increment data was available. Varying decomposition rates altered density estimates by 7 %.

New Mexico Subplots: Compared with Arizona plots, a smaller proportion of historically measured tree structures were relocated on New Mexico subplots. The number of missed tree structures ranged from 1 to 33 and the average error rate for all plots was 11.5 % (Table 14). Similar to Arizona subplots, most (85%) missed trees on New Mexico subplots were small (<30.0 cm DBH) in 1910 - 1912 and many (47%) had died or were cut prior to 1937 (Table 15). As mentioned above, a significant positive relationship existed for the number of trees originally mapped on subplots and the of trees number missed (Figure 8). In other words, if a plot historically had a greater number of trees, there was a greater chance of missing evidence of these trees (live, snag, log, stump) 90 years later.

Diameter reconstruction of historical trees that were still alive on New Mexico subplots at remeasurement overestimated DBH by an average of 1.3 % (Table 16). This was much more precise than reconstruction of live trees on Arizona plots. However, no clear trend was observed between historical size and reconstruction error on New Mexico plots (Figure 9). In contrast to Arizona subplots, DBH was underestimated on two New Mexico subplots (CIBS1A and

Table 11. Error rate (%), sample size (in parentheses), and standard deviation (SD) for diameter (DBH ≥ 10.16 cm) reconstruction of trees alive at plot establishment (1909 - 1913) but were snags or dead and downed at subplot remeasurement (1997 - 1999): Arizona subplots.

	Decay Percentile					
Subplot	25th	SD	50th	SD	75th	SD
COCS1A	60.2 (2)	76.3	40.0 (2)	68.3	26.8 (2)	63.3
COCS1B	-2.6 (1)	--	-2.1 (2)	18.7	-10.2 (2)	20.0
COCS2A	-16.9 (22)	37.5	-25.2 (25)	31.6	-26.3 (28)	33.0
COCS2B	35.0 (6)	151.2	31.6 (6)	152.2	11.1 (6)	114.0
COCS3A	52.1 (4)	62.7	40.4 (4)	46.8	26.1 (6)	43.0
COCS3B	-8.2 (1)	--	-10.8 (5)	17.7	-10.8 (6)	31.5
COCS4A	NA (0)	--	22.9 (1)	--	29.4 (3)	50.0
COCS4B	34.5 (1)	--	18.4 (1)	--	7.5 (1)	--
COCS5A2	NA (0)	--	8.0 (1)	--	1.0 (1)	--
COCS5B3	70.7 (1)	--	32.2 (3)	41.3	20.5 (3)	37.7
Average[a]	***6.9***		***-0.6***		***-6.7***	

[a]Averages weighted by sample size

Table 12. Error rate (%), sample size (in parentheses), and standard deviation (SD) for diameter (DBH ≥ 10.16 cm) reconstruction of historical trees that had been cut after original plot establishment (1909 - 1913) and were stumps at time of remeasurement (1997 - 1999): Arizona subplots.

	Cut Date					
Subplot	1910[a]	SD	1945	SD	1980	SD
COCS1A	40.6 (6)	22.1	28.4 (6)	21	15.0 (6)	19.9
COCS1B	22.1 (14)	50.6	10.2 (14)	47.6	-3.1 (14)	44.7
COCS2A	57.5 (14)	112.2	43.1 (14)	101.8	26.8 (14)	90.4
COCS2B	42.0 (14)	31.3	29.1 (14)	28.2	14.7 (14)	25.2
COCS3A	61.1 (18)	56.3	45.9 (18)	50.6	28.9 (18)	44.4
COCS3B	33.3 (21)	34.7	19.1 (21)	30.5	2.8 (21)	26.1
COCS4A	54.4 (36)	56.1	36.2 (36)	51.3	14.7 (36)	47
COCS4B	43.8 (33)	33.8	26.8 (33)	29.2	6.8 (33)	25.5
COCS5A2	7.5 (4)	23.3	-0.02 (4)	23.1	-9.4 (4)	23.1
COCS5B3	24.7 (10)	17.2	14.3 (10)	16.5	1.2 (10)	16.2
Average[b]	***43.7***		***28.7***		***11.4***	

[a]Earliest cut date tested for subplots COCS5A2 and COCS5B3 was 1914; these plots were historically established in 1913.
[b]Average weighted by sample size.

Table 13. Numbers of trees (≥ 10.16 cm DBH) for Arizona subplots reconstructed to plot establishment (1909 - 1913). Comparison shows number of historically measured trees (Estbl.), total number of trees reconstructed (Total), and the number of trees after reconstruction totals were adjusted (Adjst1 and Adjst2). Error (No. Trees) is equal to (Adjst2 - Estbl). Error (%) is equal to ((Error (No. Trees)/ Estbl)*100).

			Reconstruction		Error	Error
Subplot	Estbl.	Total	Adjst1*	Adjst2**	(No. Trees)	(%)
COCS1A	26	213	140	44	18	69.2
COCS1B	25	71	55	44	19	76.0
COCS2A	82	248	223	133	51	62.2
COCS2B	72	299	262	119	47	65.3
COCS3A	47	112	83	74	27	57.4
COCS3B	58	105	80	80	22	37.9
COCS4A	87	111	98	97	10	11.5
COCS4B	61	90	73	71	10	16.4
COCS5A2	20	81	42	37	17	85.0
COCS5B3	83	157	124	119	36	43.4

* Number adjusted by removing cut trees that were not originally tagged. These trees were likely cut prior to plot establishment or large regeneration thinned such as on COCS3A and COCS3B.

** Number adjusted by removing trees not in original ledger data but having increment core center dates of less than or equal to plot establishment date (1909 - 1913). These trees were likely larger regeneration and less than 10.16 cm DBH in 1909 - 1913.

Table 14. Number of trees (≥ 10.16 cm DBH) on Woolsey subplots in New Mexico at plot establishment (1910-1912) and the number missed during remeasurement (1998).

Subplot	Number of Trees on Subplot	Number of Trees Missed	Error (%)
CIBS1A	105	14	13.3
CIBS2A	125	18	14.4
GILAS1A	59	3	5.1
JEMS2A	89	1	1.1
JEMS3A	222	33	14.5
Average	(600)	(69)	***11.5***

Table 15. Characteristics of historically (1910 - 1912) measured trees that were missed in the field during remeasurement (1998) on New Mexico Woolsey subplots. One tree was Douglas-fir (DF in Age Class), the rest were ponderosa pine, historically recorded in blackjack (BJ) or yellow pine (YP) age classes. Historical condition was recorded on ledgers dating from 1910 - 1935.

Subplot	Age Class	Historical Diameter (cm)	Historical Condition
CIBS1A	BJ	10.7	dead 1920
CIBS1A	BJ	24.9	dead 1925
CIBS1A	BJ	26.9	dead 1930
CIBS1A	BJ	32.5	dead 1930
CIBS1A	BJ	14.0	dead 1935
CIBS1A	BJ	12.7	healthy
CIBS1A	BJ	22.4	mistletoe, unhealthy 1930
CIBS1A	BJ	12.2	suppressed
CIBS1A	BJ	19.3	suppressed, mistletoe, unhealthy 1910
CIBS1A	BJ	40.1	top dead 1920
CIBS1A	BJ	15.5	unhealthy 1930
CIBS1A	BJ/YP	22.9	dead 1920
CIBS1A	YP	27.2	dead 1920
CIBS1A	YP	28.2	mistletoe
CIBS1A	YP	33.0	mistletoe, unhealthy 1930
CIBS2A	BJ	23.6	dead 1915
CIBS2A	BJ	18.8	dead 1925
CIBS2A	BJ	19.3	dead 1925
CIBS2A	BJ	22.9	dead 1925
CIBS2A	BJ	41.7	dead 1925
CIBS2A	BJ	22.6	dead 1930
CIBS2A	BJ	18.8	healthy
CIBS2A	BJ	37.1	healthy
CIBS2A	BJ	15.2	healthy, basal scar
CIBS2A	BJ	14.5	intermediate crown class 1915
CIBS2A	BJ	18.8	intermediate crown class, basal fire scar
CIBS2A	BJ	25.4	intermediate crown class, unhealthy 1930
CIBS2A	BJ	30.0	unhealthy 1910, porcupine
CIBS2A	BJ	20.3	unhealthy 1910, suppressed
CIBS2A	BJ	21.3	unhealthy 1910, suppressed
CIBS2A	BJ	29.0	unhealthy 1915, basal scar
CIBS2A	YP	29.5	dead 1925
CIBS2A	YP	35.1	healthy
GILAS1A	BJ	20.3	dead 1932
GILAS1A	BJ	19.6	suppressed 1927 unhealthy
GILAS1A	DF	18.8	dead 1932
JEMS2A	YP	27.9	unhealthy 1911
JEMS3A	BJ	11.4	cut 1916

Table 15 (continued).

Subplot	Age Class	Historical Diameter (cm)	Historical Condition
JEMS3A	BJ	16.8	cut 1916
JEMS3A	BJ	19.3	cut 1916
JEMS3A	BJ	10.9	dead 1916
JEMS3A	BJ	26.7	dead 1921
JEMS3A	BJ	12.2	dead 1926
JEMS3A	BJ	12.7	dead 1926
JEMS3A	BJ	19.3	dead 1926
JEMS3A	BJ	26.4	dead 1926
JEMS3A	BJ	19.1	dead 1931
JEMS3A	BJ	13.5	dead 1936
JEMS3A	BJ	14.2	dead 1936
JEMS3A	BJ	11.9	healthy
JEMS3A	BJ	18.5	healthy
JEMS3A	BJ	23.9	healthy
JEMS3A	BJ	25.4	healthy
JEMS3A	BJ	38.9	healthy
JEMS3A	BJ	10.4	leaning, unhealthy 1911
JEMS3A	BJ	14.0	mistletoe 1916
JEMS3A	BJ	23.6	mistletoe 1926
JEMS3A	BJ	11.9	unhealthy 1911
JEMS3A	BJ	12.4	unhealthy 1911
JEMS3A	BJ	12.7	unhealthy 1911
JEMS3A	BJ	30.2	unhealthy 1911
JEMS3A	BJ	23.9	unhealthy 1916
JEMS3A	BJ	32.0	unhealthy 1916
JEMS3A	BJ	22.1	unhealthy 1921

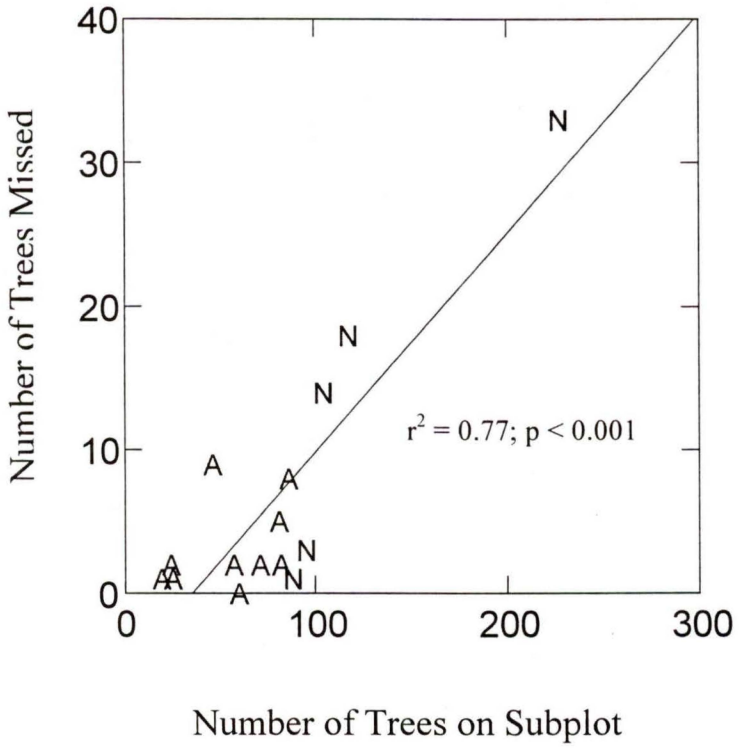

Figure 8. Relationship of the number of trees missed in the field during remeasurement (1997 - 1999) and the number of trees historically (1900 - 1913) measured on Woolsey subplots in Arizona (A) and New Mexico (N).

Table 16. Errors (%) for reconstruction estimates of historical tree diameters (≥ 10.16 cm DBH) and number (n) of live trees in analysis for Woolsey subplots in New Mexico.

Subplot	Error (%)	SD	n
CIBS1A	-0.4	23.5	42
CIBS2A	9.3	13.6	22
GILAS1A	-4.4	20.4	29
JEMS2A	2.2	18.6	44
JEMS3A	1.7	21.2	67
Average[a]	***1.3***		

[a]Average weighted by sample size (n).

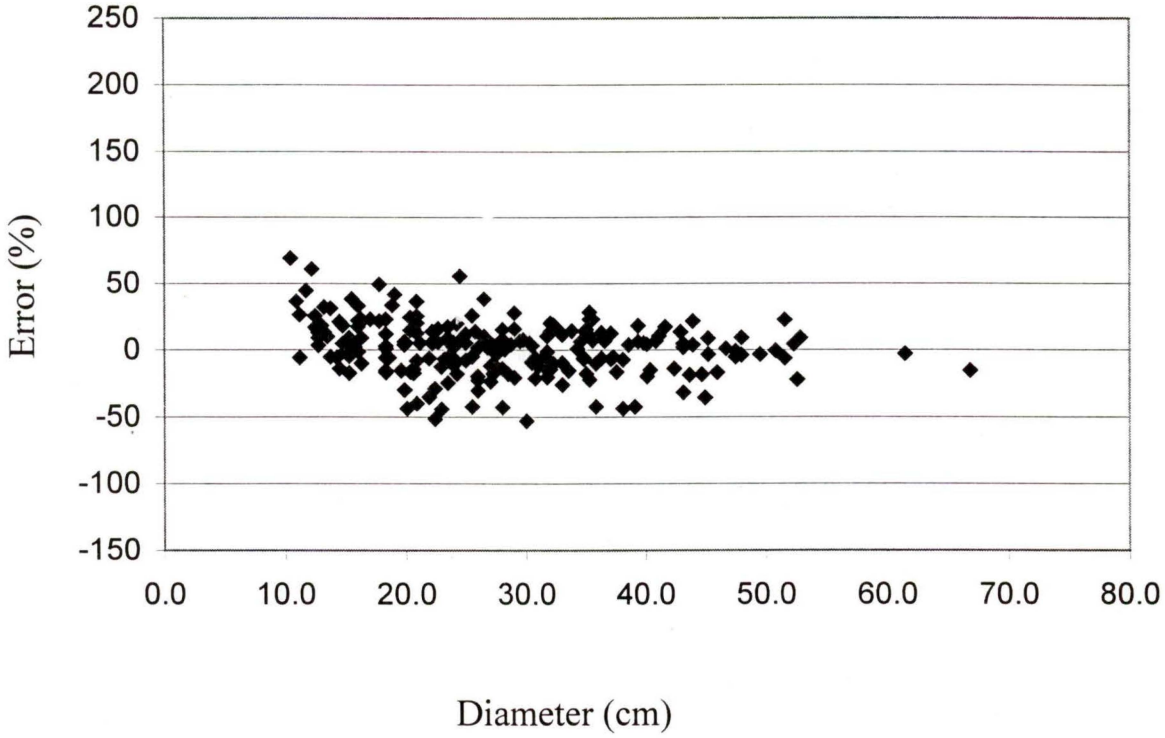

Figure 9. Relationship of error (%) and diameter for DBH reconstruction of historically measured live trees at remeasurement (1998) on New Mexico subplots. Diameter is value historically recorded for these trees.

GILAS1A). Few large errors (> 60 %) existed for diameter reconstruction of live trees on these subplots (Figure 9).

Error for diameter reconstruction of trees alive in 1910 -1912 but that were snags or dead and downed at remeasurement averaged -8.2 % for the 25th decay percentile and averaged -24.8% for the 75th decay percentile (Table 17). Sensitivity analysis showed that dead trees were most accurately reconstructed when moved through decay classes at the 25th percentile rate. All decay rates tested underestimated DBH of the historically measured trees. Varying decomposition rates by 25% altered size estimates of trees reconstructed to 1910 - 1912 from 6 to 10%. Sample size of dead structures was relatively even across New Mexico subplots.

Similar to reconstruction of Arizona subplots, diameters of historical trees on New Mexico subplots that had been cut since original plot establishment (1910 - 1912) were most accurate when the cut date in the model was set to 1980 (Table 18). This corroborates our understanding of the management histories of these plots. Most plots had some tree harvesting at least once prior to establishment (late 1800s - early 1900s) but were not to have been harvested after plot establishment (Woolsey 1911). Despite these original "rules", some tree harvesting did occur after 1910. None of the historically measured trees on GILAS1A, JEMS2A, or JEMS3A, subplots had been cut. Averaged over CIBS1A and CIBS2A, subplots with model cut date set to 1980, diameter reconstruction of cut trees overestimated DBH by 7.9%.

Similar to Arizona subplots, reconstructed tree densities on New Mexico subplots were generally higher than those recorded on historical maps (Table 19). Adjustments to reconstructed totals as explained for Arizona subplots resulted in error rates that ranged from an underestimate of 24 trees (CIBS2A) to an overestimate of 27 trees (GILAS1A) per subplot. As found for Arizona subplots, imprecise estimates of tree death dates affected the number of trees reconstructed.

Reconstruction of Presettlement Structure:

Arizona Subplots: Information gained from analysis of size reconstructions in the previous section was used to adjust model settings and estimated diameters for subplots reconstructed to fire exclusion date (1876). For Arizona subplots, the model was set to move trees through decay classes at the 50th percentile, to cut postplot trees in 1980, and to cut presettlement trees, that were not historically measured (i.e., trees harvested before plot establishment) in the year before plot establishment. The resulting DBH estimates were adjusted by applying error rates of 11.9, -0.6, and 11.4% to trees that were alive, dead and downed, and cut, respectively, at remeasurement. Resulting subplot densities ranged from 61 to 159 trees per plot (average = 136 TPH) (Table 20). Increases in density from fire exclusion to the present ranged from slight (COCS4A and COCS4B) up to 32.9-fold. On average, density increased on subplots by a factor of 8.5.

Diameter distributions (all live trees > 1.4 m in height) revealed that the largest increases were in the smallest size classes over this approximate 120-year period. Figure 10 shows a comparison of diameters for COCS1A that are representative of most subplots in Arizona (see Appendix VI for fire exclusion:present diameter distribution comparisons for all subplots). Recruitment since fire exclusion has shifted diameter distributions to negative exponential forms.

Table 17. Error rate (%), sample size (in parentheses), and standard deviation (SD) for diameter (DBH ≥ 10.16 cm) reconstruction of historically alive (1910 - 1912) trees but were snags or dead and downed at time of subplot remeasurement (1998): New Mexico subplots.

	Decay Percentile					
Subplot	25th	SD	50th	SD	75th	SD
CIBS1A	-14.2 (27)	33.5	-24.1 (24)	29.5	-30.0 (22)	24.9
CIBS2A	-8.6 (17)	46.9	-17.9 (15)	41.7	-17.5 (14)	48.0
GILAS1A	73.0 (8)	150.3	45.5 (8)	124.1	25.7 (8)	107.1
JEMS2A	-33.9 (26)	25.4	-40.7 (23)	21.4	-47.7 (23)	19.5
JEMS3A	-3.3 (37)	51.5	-14.6 (37)	41.7	-21.1 (36)	35.6
Average[a]	***-8.2***		***-18.3***		***-24.8***	

[a]Averages weighted by sample size

Table 18. Error rate (%), sample size (in parentheses), and standard deviation (SD) for diameter (DBH ≥ 10.16 cm) reconstruction of historical trees that had been cut after original plot establishment (1910 - 1912) and were stumps at time of remeasurement (1998). New Mexico subplots.

	Cut Date					
Subplot	1911[a]	SD	1945	SD	1980	SD
CIBS1A	35.1 (6)	44.1	17.4 (6)	40.7	17.6 (3)	20.4
CIBS2A	51.1 (52)	44.4	31.5 (52)	40.0	7.4 (52)	35.7
GILAS1A	NA (0)	--	NA (0)	--	NA (0)	--
JEMS2A	NA (0)	--	NA (0)	--	NA (0)	--
JEMS3A	NA (0)	--	NA (0)	--	NA (0)	--
Average[b]	***49.4***		***30.0***		***7.9***	

[a]Earliest cut date tested for subplots GILAS1A was 1913 and for JEMS2A and JEMS3A was 1912; these plots were established in 1912 and 1911, respectively.

[b]Average weighted by sample size.

Table 19. Numbers of trees (≥ 10.16 cm DBH) for New Mexico subplots reconstructed to plot establishment (1910 - 1912). Comparison shows number of historically measured trees (Estbl.), total number of trees reconstructed (Total), and the number of trees after reconstruction totals were adjusted (Adjst1 and Adjst2). Error (No. Trees) is equal to (Adjst2 - Estbl). Error (%) is equal to ((Error (No. Trees)/ Estbl)*100).

		Reconstruction			Error	Error
Subplot	Estbl.	Total	Adjst1*	Adjst2**	(No. Trees)	(%)
CIBS1A	105	149	120	117	12	11.4
CIBS2A	125	130	103	101	-24	-19.2
GILAS1A	59	152	91	86	27	45.8
JEMS2A	89	152	107	103	14	15.7
JEMS3A	222	239	226	210	-12	-5.4

* Number adjusted by removing cut trees that were not originally tagged. These trees were likely cut prior to plot establishment or large regeneration that was thinned.

** Number adjusted by removing trees not in original ledger data but having increment core center dates of less than or equal to plot establishment date (1910 - 1912). These trees were likely larger regeneration that were less than 10.16 cm DBH in 1910 - 1912.

Table 20. Total number of live trees on Woolsey subplots in Arizona reconstructed to fire exclusion date (1876) and at subplot remeasurement (1997 - 1999).

Subplot	Fire Exclusion Date (1876)	Remeasurement Date (1997 - 1999)
COCS1A	117	953
COCS1B	61	2009
COCS2A	146	845
COCS2B	127	1456
COCS3A	94	691
COCS3B	106	289
COCS4A	105	110
COCS4B	90	107
COCS5A2	112	1013
COCS5B3	159	813

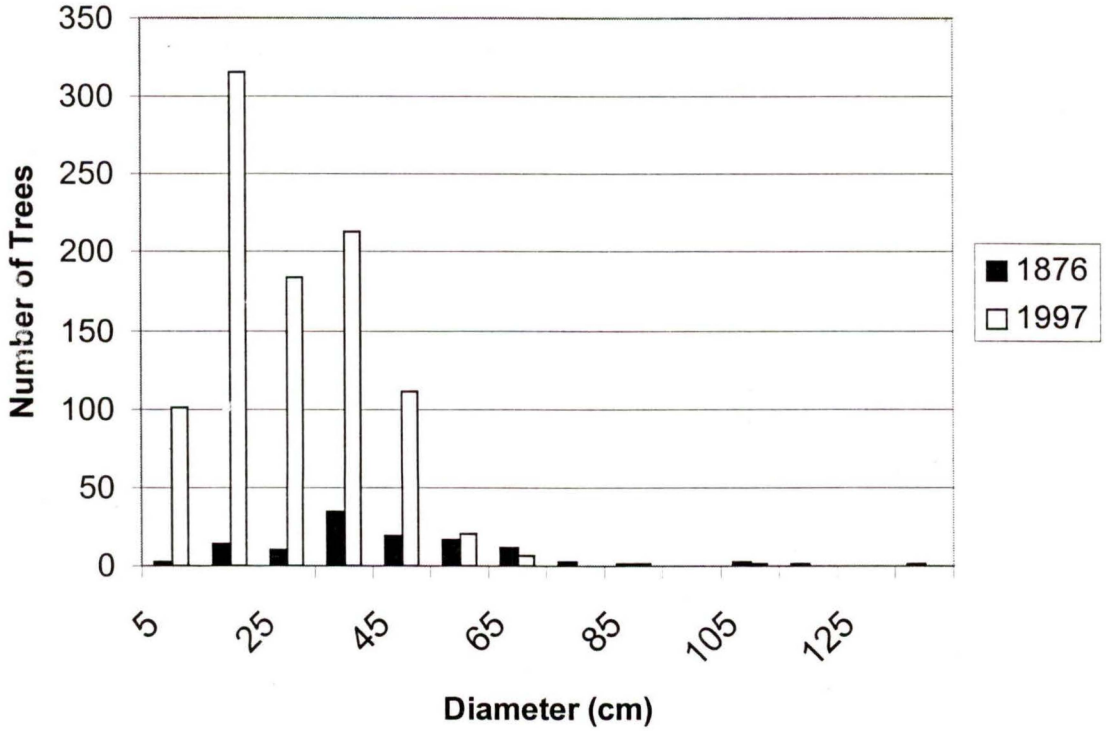

Figure 10. Diameter distribution for reconstruction of Arizona subplot COCS1A for fire exclusion date (1876) compared with remeasurement date (1997).

On Arizona subplots, species composition has remained similar to conditions at fire exclusion. Subplot COCS2A showed a slight increase in the occurrence of Gambel oak from none in presettlement reconstructions to 1.7 % at remeasurement. In contrast, plots COCS5A2 and COCS5B3 showed decreases in Gambel oak of 7.5 and 1.3 %, respectively, compared with fire exclusion date reconstructions.

New Mexico Subplots: Error analysis for reconstruction of New Mexico subplots to establishment (1910 - 1912) indicated the most accurate estimates of DBH were gained when model parameters were set to the 25th decay percentile and 1980 tree cut date. Similar to Arizona reconstructions, cut date for presettlement trees that were not historically measured (i.e., trees harvested before plot establishment) were set for the year before plot establishment. Diameter estimates from reconstruction to fire exclusion date (1890) with these model settings were then adjusted by the error rates found in the earlier analyses. Estimates were adjusted by applying error rates of 1.3, -8.2, and 7.9% to trees that, at remeasurement, were alive, snags or dead and downed, and cut, respectively. Resulting subplot densities ranged from 142 to 298 trees per plot (≈TPH) (Table 21). Increases in density from fire exclusion reconstruction to remeasurement ranged up to 10.6-fold. All New Mexico subplots showed increases in tree density since fire exclusion.

Similar to Arizona subplots increases in density on New Mexico subplots were mainly due to recruitment of smaller size classes. Figure 11 shows a comparison of diameters for CIBS1A that was typical for most subplots in New Mexico (see Appendix VI for fire exclusion:present diameter distribution comparisons for all subplots).

In contrast to Arizona subplots, species composition (all live trees > 1.4 m in height) on New Mexico subplots have shifted since fire exclusion. Subplots historically dominated by ponderosa pine are presently mixed stands of ponderosa pine, Gambel oak, Douglas-fir and southwestern white pine. In terms of composition, subplot proportions of ponderosa have decreased (9.4 - 44.0% decrease in proportion of subplot tree density). The most dramatic changes occurred on subplot GILAS1A where the proportion of ponderosa pine decreased by 44% whereas that of Douglas-fir increased by 32.8% since fire exclusion.

Discussion

Changes since Subplot Establishment:

Significant structural changes have occurred on nearly all historical plots that we remeasured since their establishment early in the 20th century. As reported in other studies (Cooper 1960, White 1985, Covington et al. 1994, Covington and Moore 1994a, Fulé et al. 1997, Mast et al. 1999, Moore et al. 1999), tree regeneration associated with overgrazing, logging, climatic events, and the elimination of frequent fire in the region has resulted in dense ponderosa pine stands dominated by small diameter trees. It is probable that many postsettlement seedlings and saplings were present on the Woolsey plots at the time of establishment. However, no trees under 10.16 cm (4 in) DBH were historically measured. In fact, several stem maps made in 1915 show areas of dense regeneration (e.g., Appendix I; COCS1A polygons with crosshatching). All subplots remeasured in this study showed increases in tree density, particularly in smaller diameter classes, except subplots COCS4A and COCS4B in Arizona. COCS4A and COCS4B are located on skeletal, volcanic soils derived from the igneous materials and cinders associated with geologically recent volcanic activity in the area. Soil characteristics combined with

Table 21. Total number of live trees on Woolsey subplots in New Mexico reconstructed to fire exclusion date (1890) and at subplot remeasurement (1998).

Subplot	Fire Exclusion Date (1890)	Remeasurement Date (1998)
CIBS1A	178	1626
CIBS2A	149	578
GILAS1A*	142	1509
JEMS2A	163	733
JEMS3A	298	746

* Subplot size = 0.73 ha

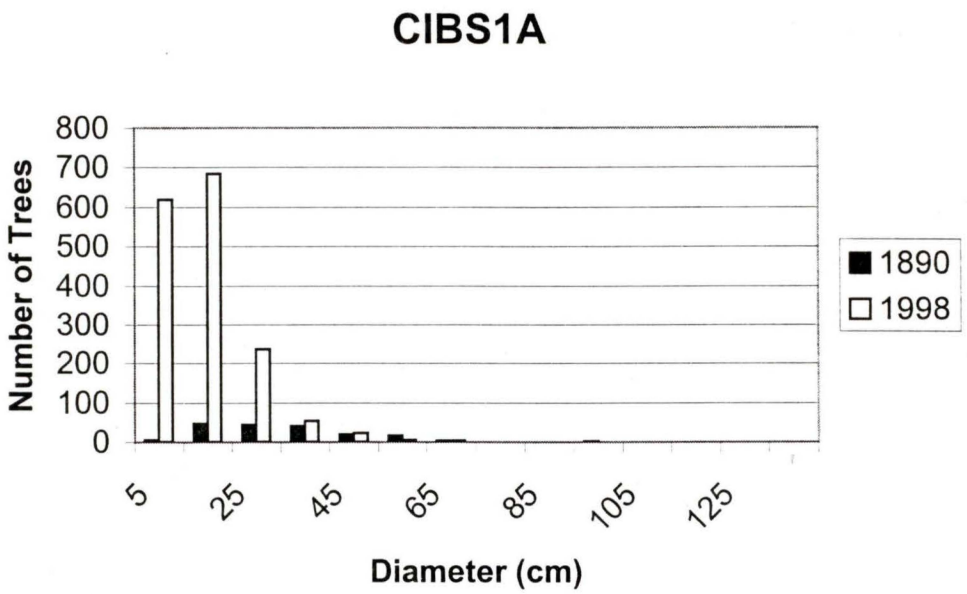

Figure 11. Diameter distribution for reconstruction of New Mexico subplot CIBS1A for fire exclusion date (1890) compared with remeasurement date (1998).

microclimatic extremes on these subplots likely constrained regeneration even after frequent fire had been excluded from the area.

Subplots in Arizona did not show large shifts in species composition and remained dominated by ponderosa pine overstories over the ± 90-year period. This was not the case for subplots in New Mexico. Higher elevation subplots that contained Douglas-fir showed increasing dominance by this species and appear to be undergoing a shift to a mixed-conifer forest type. One historical plot that was remeasured but not reported here had already completed converted from ponderosa pine to mixed conifer stands (Pecos S1A; Table 1). Conversion of forest communities dominated by fire resistant trees to those supporting dense populations of shade tolerant, fire sensitive species due to the exclusion of indigenous disturbance processes has been reported in other forest types of the western U.S. (e.g., Covington et al. 1994).

On most subplots that we remeasured in Arizona (1997 - 1999) and New Mexico (1998), very little disturbance, outside of individual tree selection harvest, has occurred since plot establishment (1909 -1913). We found no evidence of intense fire although the 1977 La Mesa wildfire burned large areas near JEMS3A and injured some of the trees on this subplot. A road (NM #4) destroyed the northern portion of JEMS3A and trees were cut to stop the La Mesa fire. Only a portion (0.73 ha) of GILAS1A could be used because of road construction. A relocated New Mexico subplot, GILAS1B, could not be used because it was destroyed by wildfire. Precommercial thinning had occurred on Arizona subplots COCS3A and COCS3B. In addition to the plots we remeasured, GILAS1B (New Mexico) could not be used because it was destroyed by wildfire. A residential area of Los Alamos mostly destroyed JEMS1A in the 1950s. This plot and JEMS2A were both burned in the Cerro Grande fire (spring 2000). JEMS1A was lightly to moderately scorched whereas JEMS2A was moderately to severely burned. Lastly, Pecos S1A and Pecos S2A (Table 1) were burned in the Viveash Fire of spring 2000. The condition of these plots is unknown.

Evaluation of Reconstruction Techniques:

Evaluation of reconstruction techniques revealed several key sources of error. These included field identification of historical trees and tree structures, size reconstruction of live trees, and determination of tree death dates. Tree structures on the ponderosa pine subplots were readily identified in the field after ± 90 years. Missed trees resulted in an average underestimate of plot density by 5.7 % or about 3 TPH (1.2 trees per acre) in Arizona and 11.5 % or about 14 TPH (5.7 trees per acre) in New Mexico. It appeared that the number of trees occurring on subplots in the past affected our ability to relocate all of the evidence. That is, the greater the tree density in the past, the greater chance of missing tree structure evidence. Other factors that may affect success rate of identification include disturbance such as fire, time, and experience level of personnel.

The reconstruction model tested in this analysis tended to overestimate tree diameters for live trees (11.9 % Arizona subplots, 1.3 % New Mexico subplots). Better precision was found for reconstruction of New Mexico subplots compared with that for Arizona subplots. For live trees, slightly greater inaccuracies were produced for smaller size classes in Arizona but not in New Mexico. Possible explanations for live-tree diameter reconstruction errors include model equations used to predict bark thickness and DBH from DSH (Myers 1963, Hann 1976), unusable increment cores, particularly for trees that were especially fast- or slow-growing, and eccentricity of tree bases. Historical DBH was underestimated for snags and dead and downed trees in Arizona (-0.6 %) and New Mexico (-8.2 %). Moving trees through decay classes at the 50th percentile reconstructed diameters most accurately in Arizona. However, a slower decay rate

(25th percentile) reconstructed historical DBH most accurately for New Mexico subplots. These differences may be related to decay functions used in the reconstruction model specific to ponderosa pine forests whereas greater overstory species diversity existed on New Mexico subplots (Table 7). In addition, the New Mexico subplots represented a greater range of habitat types from the more mesic GILAS1A to the more xeric CIBS2A. Although prediction of tree death date is difficult due to vagaries in the factors affecting snag and log longevity and condition, the DBH estimates provided by the reconstruction model were relatively accurate. The reconstruction model also overestimated diameters of historical trees that had been cut since plot establishment. For both Arizona and New Mexico subplots, setting a model cut date to 1980 most accurately reconstructed historical DBH (overestimate of 11.4 and 7.9 % for Arizona and New Mexico subplots, respectively). In our analysis, global cut dates were set in the model although in reality, trees on the subplots were not all cut in the same year. This undoubtedly affected DBH reconstruction errors. Cut dates for harvested "cohorts" could be individually coded in the model using additional information not examined in this study such as harvest records (e.g., timber atlases) and stump decay classes.

Overestimation of DBH coupled with death date and cut date uncertainties lead to overestimates of past subplot density. Diameters of trees that were not historically measured due to their small size (< 10.16 cm DBH) were overestimated and thus these trees became included in reconstructed subplot totals, inflating estimated subplot densities. Subplot density overestimates were greater for Arizona subplots than for those in New Mexico. After adjustments, plot density of Arizona subplots was still overestimated by 10 to 51 trees TPH. On New Mexico subplots, adjustments made to reconstructed densities resulted in a relatively accurate estimate of past stand conditions; error ranged from an underestimate of 24 to an overestimate of 27 TPH. Refinement of decay functions may allow better precision in plot density reconstruction.

The reconstruction techniques evaluated in this study appear to be robust and useful for estimating past forest structural characteristics. Although our reconstruction model was used generally, adjustments could be made for specific sites using relationships developed from site-specific field data. The techniques allow a better understanding of reference conditions in ponderosa pine forests of the Southwest.

Reconstruction of Conditions at Fire Exclusion:

Reconstruction of plot conditions at fire exclusion (1876 - 1890) showed changes in tree density and species composition. Similar to patterns observed since plot establishment from 1909 to 1913, the majority of structural changes is related to recruitment of small diameter trees. In New Mexico, many of these trees were shade tolerant species such as Douglas-fir or sprouting species such as Gambel oak. Subplot conditions at fire exclusion were generally characterized by tree size distributions often interpreted as indicative of all-aged stands. However, detailed age data from intensive analysis near subplot COCS1B indicate an uneven aged presettlement structure (Mast et al. 1999). This structure of the late 1800s and early 1900s appears to have been replaced by negative exponential distributions characteristic of uneven-aged stands dominated by large numbers of younger trees. White (1985) found that younger age classes dominated the distribution of live presettlement tree ages at Gustav A. Pearson Natural Area (GPNA), a site near some of our Arizona Woolsey plots (COCS1A, COCS1B, COCS2A, and COCS2B). Forty-nine percent of the trees sampled were from 32 to 61-years-old in 1876. Mast et al. (1999) point out the need to include dead structures in presettlement forest reconstruction. On the same site sampled by White (1985), Mast et al. (1999) found a relatively flat presettlement age distribution, indicating an all-aged forest structure. All-aged presettlement structure in northern Arizona

ponderosa pine forests has been also reported elsewhere (Cooper 1960, Covington and Moore 1994a). In our study, we used historical data to adjust our reconstruction estimates for tree diameter and density. Although there is only a weak relationship between tree diameter and age, we found relatively flat diameter distributions for forest structure at fire exclusion. We did not collect age data for dead material in this study, thus actual age distribution of forests at fire exclusion could not be properly evaluated.

Tree densities on subplots reconstructed to fire exclusion dates ranged from 61 to 159 TPH on Arizona subplots and from 149 to 298 TPH on New Mexico subplots. These values are slightly greater than presettlement tree densities reported by other research (Woolsey 1911, White 1985, Covington and Moore 1994a, Covington and Moore 1994b, Fulé et al. 1997, Mast et al. 1999). For example, Woolsey (1911) reported tree densities in virgin stands near the Arizona plots that ranged from 25 to 40 TPH in the early 1900s. Although these surveys only included trees greater than 10.16 cm (4 in) DBH, Woolsey (1911) stated that there were large areas on the Coconino National Forest where reproduction was entirely lacking and only 22% of the land area had good reproduction. On the Cibola and Jemez National Forests in New Mexico, Woolsey (1911) reported 56 and 88 TPH $\geq$ 10.16 cm DBH, respectively, in stands of ponderosa pine. Slightly higher presettlement densities have been estimated, ranging from 56 - 60 TPH near Woolsey plots in Arizona (Covington and Moore 1994b, Mast et al. 1999).

Our selection of a specific date for these reconstructions does not assume that presettlement forests were not dynamic. Rather, it implies that forest conditions at that time were reasonably representative of conditions that existed over recent evolutionary time although changes in climate, human, and animal populations have occurred (Moore et al. 1999). This implication is supported by long-term patterns of presettlement fire regimes that were relatively consistent over 200 - 300 years (Swetnam and Baison 1996, Fulé 1997). These fire histories comprised a period of drier, colder climate during the Little Ice Age (ca 1400 - 1850) (Delcourt and Delcourt 1988) and little information exists regarding more recent fire return intervals in areas not affected by postsettlement grazing, logging, and fire suppression (Fulé et al. 1997). Additional support of fire exclusion as an appropriate reference date is found in evidence of steady tree regeneration patterns for 300 years reported at GPNA (Mast et al. 1999). Similarly, diameter distributions from our reconstructions to fire exclusion dates suggest that regeneration occurred in pulses. However, these events were orders of magnitude less than the postsettlement regeneration pulse of 1919 (Savage et al. 1996). Constraints on presettlement tree regeneration including frequent low-intensity fire and herbaceous interference were persistent influences throughout the recent past (Cooper 1960, White 1985, Covington and Moore 1994). Thus the disturbance regime, forest density, and the model relating these two, support the assumption that forest structure around the fire exclusion date was representative of presettlement conditions at least over several centuries (however, some unique conditions may apply to Gambel oak and aspen (*Populus tremuloides* Michx.) in the Southwest (see Fulé et al. 1997 for discussion).

Future directions:

Range of natural variability: The Woolsey plot network, containing the oldest measured forest structural data in the Southwest and covering a broad geographic range is an ideal starting point for quantifying the range of natural variability (RNV) and changes over time in ponderosa pine forests. But the 15 plots that were measured and reported here are insufficient for quantifying RNV across the diverse conditions of the Southwest (Moir unpublished report, see Appendix VII). The greatest strength of this data set, addressed in the study objectives, lies in the remeasurement of historical plots and the testing of techniques for reconstruction of past forest

structure, complementing the intense sampling we and others are currently carrying out at several sites (e.g., Mt Trumbull, Kaibab Plateau, Camp Navajo, Ft. Valley, Gila National Forest, etc.). However, we plan to explore broader questions about the extent to which data from the Woolsey plots may help characterize the RNV in subsequent studies.

Trends observed in the data set can help support the generation of testable hypotheses about past and present variability in southwestern forests. The validated reconstruction models developed under objectives 2 and 3, in turn, will help serve as one tool for investigating these hypotheses in further studies.

Applications for Restoration and Ecosystem Management: The final question is how to apply these results to enhance ecological understanding and management of southwestern forests. The basic data on the RNV and changes since settlement on this small set of historical plots, with appropriate understanding of the variability, error, and limitations of these estimates, can provide insights into reference conditions and ecosystem change, the starting point for ecosystem management planning (Kaufmann et al. 1994). For example, further research could be aimed at the effectiveness of using historical data to define management of spatial patterns and size distributions of trees. These data also serve as a guide to coarse-scale planning for further research in restoration treatments. For example, thinning may be a key treatment in some areas while old-growth tree protection may be especially important in others. Finally, the results suggest development of future research and operational monitoring strategies for ecological restoration treatments (Covington et al. 1997, Moore et al. 1999), where such treatments are deemed advisable.

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Literature Cited

Avery, C.C., F.R. Larson, and G.H. Schubert. 1976. Fifty-year records of virgin stand development in southwestern ponderosa pine. USDA Forest Service General Technical Report RM-22, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Barton, A.M. 1993. Factors controlling plant distributions: drought, competition, and fire in montane pines in Arizona. Ecological Monographs 63(4):367-397.

Biswell, H.H. 1972. Fire ecology in ponderosa pine--grassland. Proceedings of the Tall Timbers Fire Ecology Conference 12:69-96.

Conkle, M.T., and W.B. Critchfield. 1988. Genetic variation and hybridization of ponderosa pine. Pages 27-44 in Baumgartner, D.M., and J.E. Lotan (eds.), Ponderosa Pine: The Species and Its Management. Symposium Proceedings, September 29-October 1, 1987, Spokane, WA. Washington State University.

Cooper, C.F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. Ecology 42:493-499.

Covington, W.W., and M.M. Moore. 1994a. Southwestern ponderosa forest structure and resource conditions: changes since Euro-American settlement. Journal of Forestry 92(1):39-47.

Covington, W.W., and M.M. Moore. 1994b. Postsettlement changes in natural fire regimes and forest structure: ecological restoration of old-growth ponderosa pine forests. Journal of Sustainable Forestry 2:153-181.

Covington, W.W., and S.S. Sackett. 1992. Spatial variation in soil mineral nitrogen following prescribed burning in ponderosa pine. Forest Ecology and Management 54:175-191.

Covington, W.W., P.Z. Fulé, M.M. Moore, S.C. Hart, T.E. Kolb, J.N. Mast, S.S. Sackett, and M.R. Wagner. 1997. Restoration of ecosystem health in southwestern ponderosa pine forests. Journal of Forestry 95(4):23-29.

Covington, W.W., R.L. Everett, R.W. Steele, L.I. Irwin, T.A. Daer, and A.N.D. Auclair. 1994. Historical and anticipated changes in forest ecosystems of the Inland West of the United States. Journal of Sustainable Forestry 2:13-63.

Delcourt, H. R., and P. A. Delcourt. 1988. Quaternary landscape ecology: relevant scales in space and time. Landscape Ecology 2:23-44.

Dieterich, J. H., and T. W. Swetnam. 1984. Dendrochronology of a fir-scarred ponderosa pine. Forest Science 30:238-247.

Fritts, H.C., and T.W. Swetnam. 1989. Dendroecology: a tool for evaluating variations in past and present forest environments. Advances in Ecological Research 19:111-188.

Fulé, P.Z., W.W. Covington, and M.M. Moore. 1997. Determining reference conditions for ecosystem management in southwestern ponderosa pine forests. Ecological Applications 7(3):895-908.

Graybill, D. A. 1987. Unpublished tree-ring chronologies AZ521 and AZ547. Archived at the National Geophysical Data Center, World Data Center-A for Paleoclimatology, Boulder, CO.

Hann, D.W. 1976. Relationship of stump diameter to diameter at breast height for seven tree species in Arizona and New Mexico. USDA Forest Service Research Note INT-212, Intermountain Forest and Range Experiment Station, Ogden, UT.

Kaufmann, M.R., R.T. Graham, D.A. Boyce, Jr., and 8 others. 1994. An ecological basis for ecosystem management. USDA Forest Service General Technical Report RM-246, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Kilgore, B. M. 1981. Fire in ecosystem distribution and structure: western forests and scrublands. Pages 58-89 in Fire Regimes and ecosystem properties. USDA Forest Service General Technical Report WO-26, Washington, D.C. 594 pages.

Kolb, T.E., M.R. Wagner, and W.W. Covington. 1994. Concepts of forest health. Journal of Forestry 92:10-15.

Maser, C., R. G. Anderson, K. Cromack, Jr., J. T. Williams, and R. E. Martin. 1979. Dead and down woody material. pp. 78-95 *In* Wildlife habitats in managed forests -- the Blue Mountains of Oregon and Washington. USDA Agricultural Handbook 553, Washington, D.C.

Mast, J.N., P.Z. Fulé, M.M. Moore, W.W. Covington, and A.E.M. Waltz. 1999. Restoration of presettlement age structure of an Arizona ponderosa pine forest. Ecological Applications 9:228-239.

McCune, B. 1988. Ecological diversity in North American pines. American Journal of Botany 75(3):353-368.

Minnich, R.A., M.G. Barbour, J.H. Burk, and R.F. Fernau. 1995. Sixty years of change in Californian conifer forests of the San Bernadino Mountains. Conservation Biology 9(4):902-914.

Moore, M. M., W. W. Covington, and P. Z. Fulé. 1999. Reference conditions and ecological restoration: a southwestern ponderosa pine perspective. Ecological Applications 9:166-1277.

Myers, C.A. 1963. Estimating past diameters of ponderosa pine in Arizona and New Mexico. USDA Forest Service Research Note RM-7. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Pearson, G. A. 1923. Natural reproduction of western yellow pine in the Southwest. USDA, Forest Service. Bulletin No. 105. Washington, D. C. 143 p.

Pearson, G. A. 1933. A twenty year record of changes in an Arizona pine forest. Ecology 4:272-285.

Pearson, G. A. 1950. Management of ponderosa pine in the Southwest. USDA, Forest Service, Agric. Monograph No. 6. 218 p.

Rogers, J.J., J.M. Prosser, L.D. Garrett, and M.G. Ryan. 1984. ECOSIM: A system for projecting multiresource outputs under alternative forest management regimes. USDA Forest Service, Administrative Report, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Savage, M, P.M. Brown, and J. Feddema. 1996. The role of climate in a pine forest regeneration pulse in the southwestern United States. Ecoscience 3(3):310-318.

Stokes, M.A., and T.L. Smiley. 1968. An introduction to tree-ring dating. University of Chicago Press, Chicago.

Swetnam, T.W., and C.H. Baisan. 1996. Historical fire regime patterns in the southwestern United States since AD 1700. Pages 11-32 in Allen, C.D. (ed.), Proceedings of the 2nd La Mesa Fire Symposium. USDA Forest Service General Technical Report RM-GTR-286, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Swetnam, T.W., and J.L. Betancourt. 1990. Fire--Southern Oscillation relations in the southwestern United States. Science 249:1017-1020.

Swetnam, T. W., and J. H. Deiterich. 1985. Fire history of ponderosa pine forests in the Gila Wilderness, New Mexico. Pages 390 - 397 in Lotan, J. E., B. M. Kilgore, W. C. Fischer, and R. W. Mutch (tech. coords.), Proceedings--Symposium and Workshop on Wilderness Fire. USDA Forest Service General Technical Report INT-182, Intermountain Forest and Range Experiment Station, Ogden, UT.

Thomas, J.W., R.G. Anderson, C. Maser, and E.L. Bull. 1979. Snags. Pages 60-77 in Wildlife habitats in managed forests--the Blue Mountains of Oregon and Washington. USDA Agricultural Handbook 553, Washington, D.C.

Touchan, R., C. D. Allen, and T. W. Swetnam. 1996. Fire history and climate patterns in ponderosa pine and mixed conifer forests of the Jemez Mountains, northern New Mexico. In: Allen, C. D. (ed.), Proceedings of the 2nd La Mesa Fire Symposium. USDA Forest Service General Technical Report RM-GTR-286, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Veblen, T.T., and D.C. Lorenz. 1991. The Colorado Front Range. A century of ecological change. University of Utah Press, Salt Lake City, Utah.

Weaver, H. 1957. Effects of prescribed burning in ponderosa pine. Journal of Forestry 55:133-138.

White, A.S. 1985. Presettlement regeneration patterns in a southwestern ponderosa pine stand. Ecology 66(2):589-594.

Williams, J.T., R.G. Schmidt, R.A. Norum, P.N. Omi, and R.G. Lee. 1993. Fire-related considerations and strategies in support of ecosystem management. USDA Forest Service Staffing Paper, Washington, D.C.

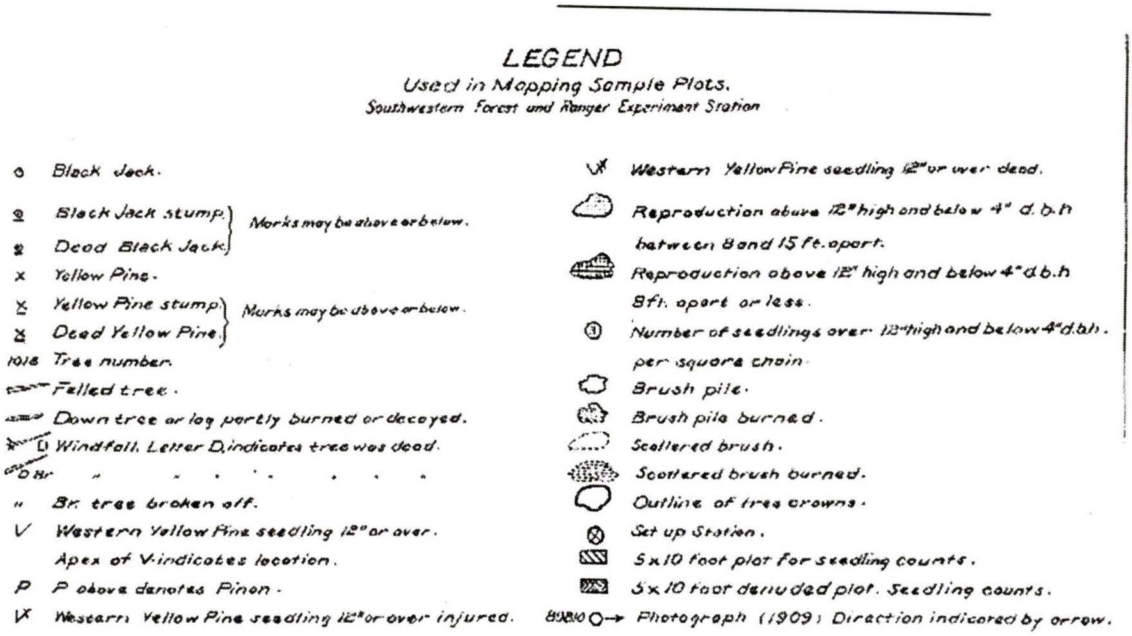
Woolsey, T. S., Jr. 1911. Western yellow pine in Arizona and New Mexico. USDA, Forest Service Bulletin 101. 64 p.

Woolsey, T. S., Jr. 1912. Permanent sample plots. Forest Quarterly 10:38-44.

Appendix I:

Scanned images of historical maps

Note: Remeasured subplot areas are outlined in bold.


LEGEND
Used in Mapping Sample Plots.
Southwestern Forest and Ranger Experiment Station
Black Jack.
Black Jack stump.
Dead Black Jack.
Marks may be above or below.
Yellow Pine.
Yellow Pine stump.
Dead Yellow Pine.
Marks may be above or below.
1018 Tree number.
Felled tree.
Down tree or log partly burned or decayed.
Windfall. Letter D indicates tree was dead.
Br. tree broken off.
Western Yellow Pine seedling 12" or over.
Apex of V indicates location.
P above denotes Pinon.
Western Yellow Pine seedling 12" or over injured.
Western Yellow Pine seedling 12" or over dead.
Reproduction above 12" high and below 4" d.b.h between 8 and 15 ft. apart.
Reproduction above 12" high and below 4" d.b.h 8 ft. apart or less.
Number of seedlings over 12" high and below 4" d.b.h. per square chain.
Brush pile.
Brush pile burned.
Scattered brush.
Scattered brush burned.
Outline of tree crowns.
Set up Station.
5 x 10 foot plot for seedling counts.
5 x 10 foot denuded plot. Seedling counts.
Photograph (1909) Direction indicated by arrow.

Supplementary legend for historical maps of Coconino plots.

U.S. DEPARTMENT OF AGRICULTURE

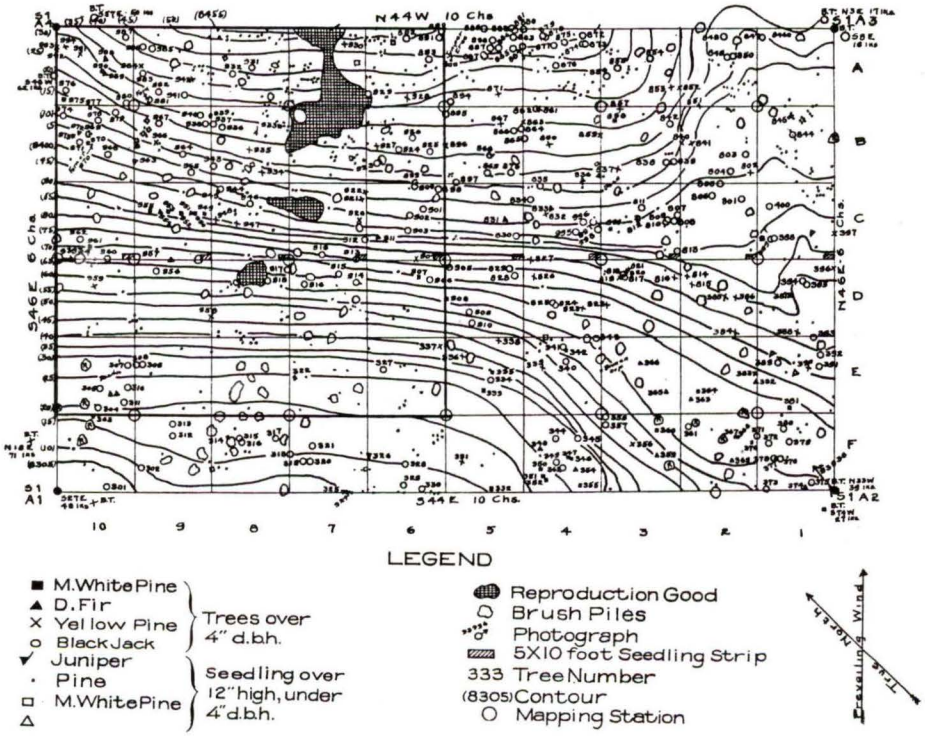
FOREST SERVICE

REPRODUCTION SAMPLE PLOT S-1-A

Becker-Mactavish Timber Sale Sept.9,1910 San Mateo Div., DATIL NATIONAL FORES
NEW MEXICO

T.5S.,R7 W.,N.M.P.M. Sec.11, S.E.Qur., Variation 13°30'E. Scale: 1 inch = 1 chain
Contour interval 5ft. by Aneroid

December 3,1910
Mapped by H.D.Burrall
Title by F.C.Keefer
Area:6 Acres



Cibola S1A (CIBS1A)

EXHIBIT O

U S DEPARTMENT OF AGRICULTURE

FOREST SERVICE

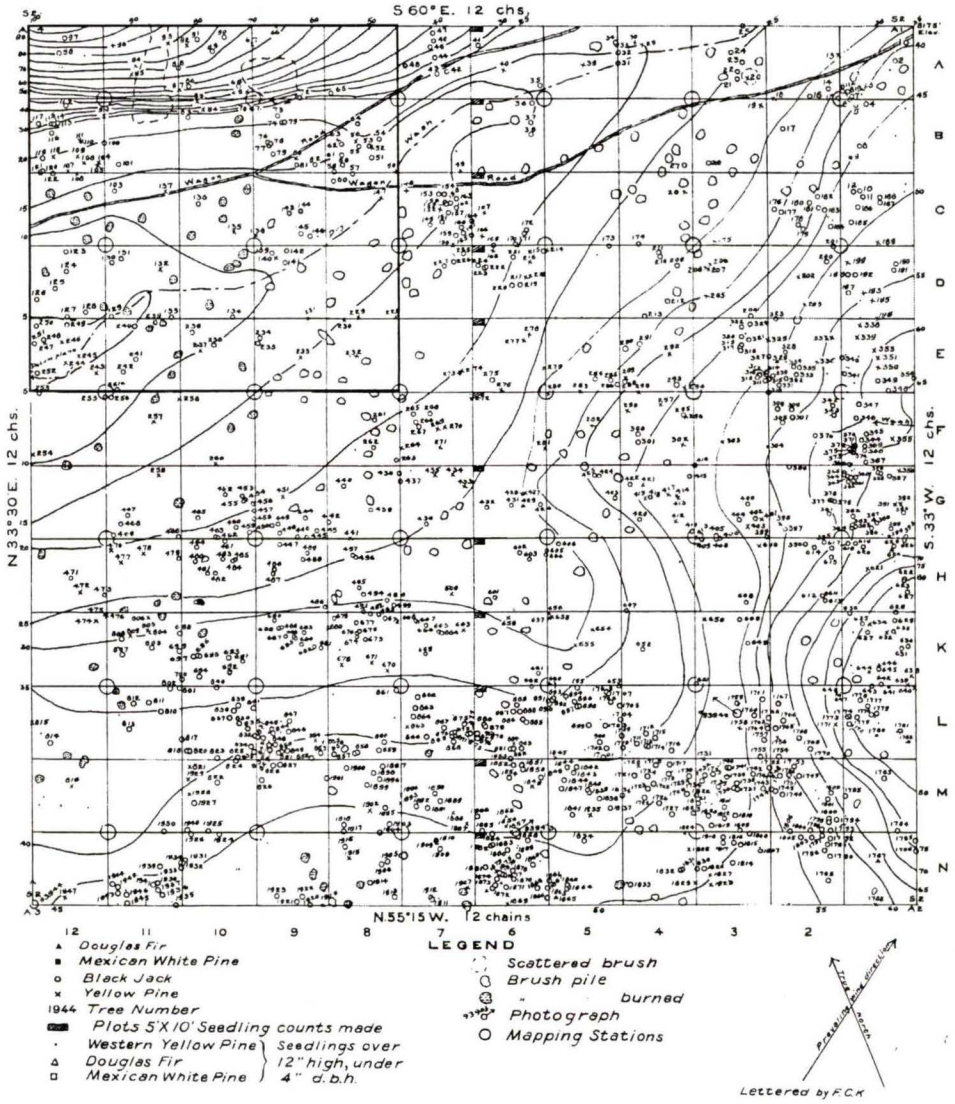
REPRODUCTION SAMPLE PLOT S-2-A

Ranch Supply Co. Timber Sale 2-27-'07 San Mateo Div., DATIL NATIONAL FOREST
T. 5 S., R. 7 W., N.M.P.M. Section 9, N.W. Quarter. Variation 13°30'E. Scale 1 inch = 1 chain
Contour Interval 5 ft. Datum plane 4.70 chains S.33°30'W. from S-2-A-4

Dec. 3, 1910

Mapped by H.D.B

Area: 14.4 A.



Cibola S2A (CIBS2A)

PROJECT Mc-2

Sample Plot S1 - A, Coconino National Forest

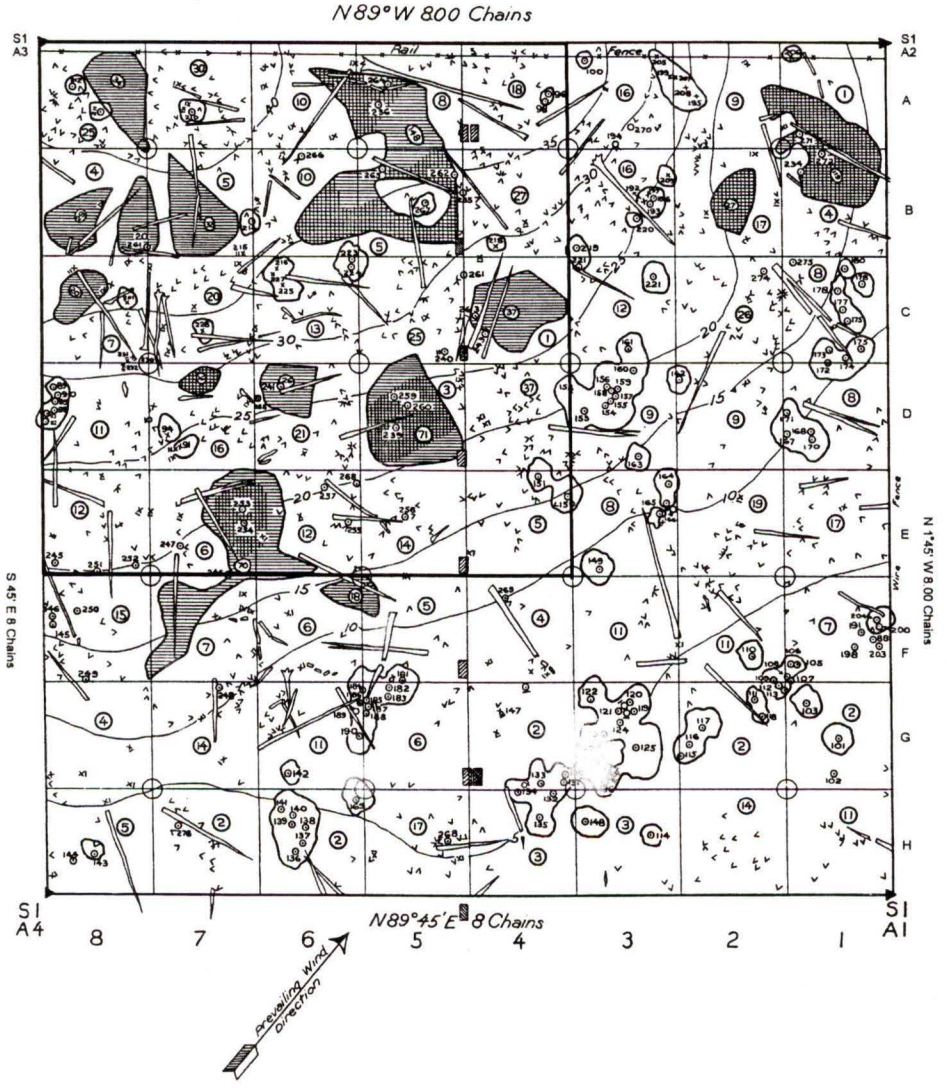
Location, Sec. 27 T22 N. R.6 E. G.and S. R. M.

Plot established, fall 1909. Logged, summer 1894

Datum Plane, S1 - A1 Contour interval - 5 ft.

Mapped by C.N. Hammond, October, 1915

Scale: 1 in. = 1 ch.



Coconino S1A (COCS1A)

PROJECT Mc-2.

Sample Plot S1 - B. Coconino National Forest

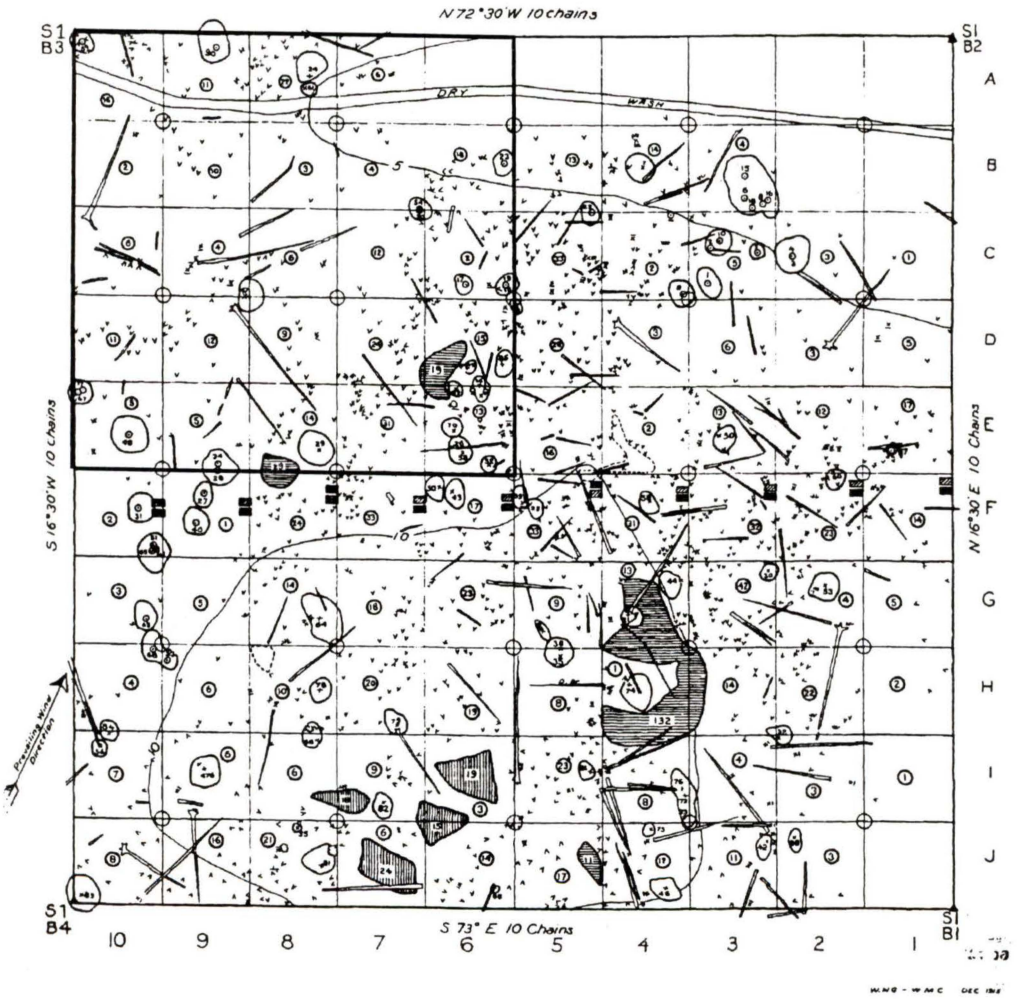
Location SW 4 Sec. 27 T. 22 N. R. 6 E., G. and S. R. M.

Plot established, fall 1909. Logged, summer 1894

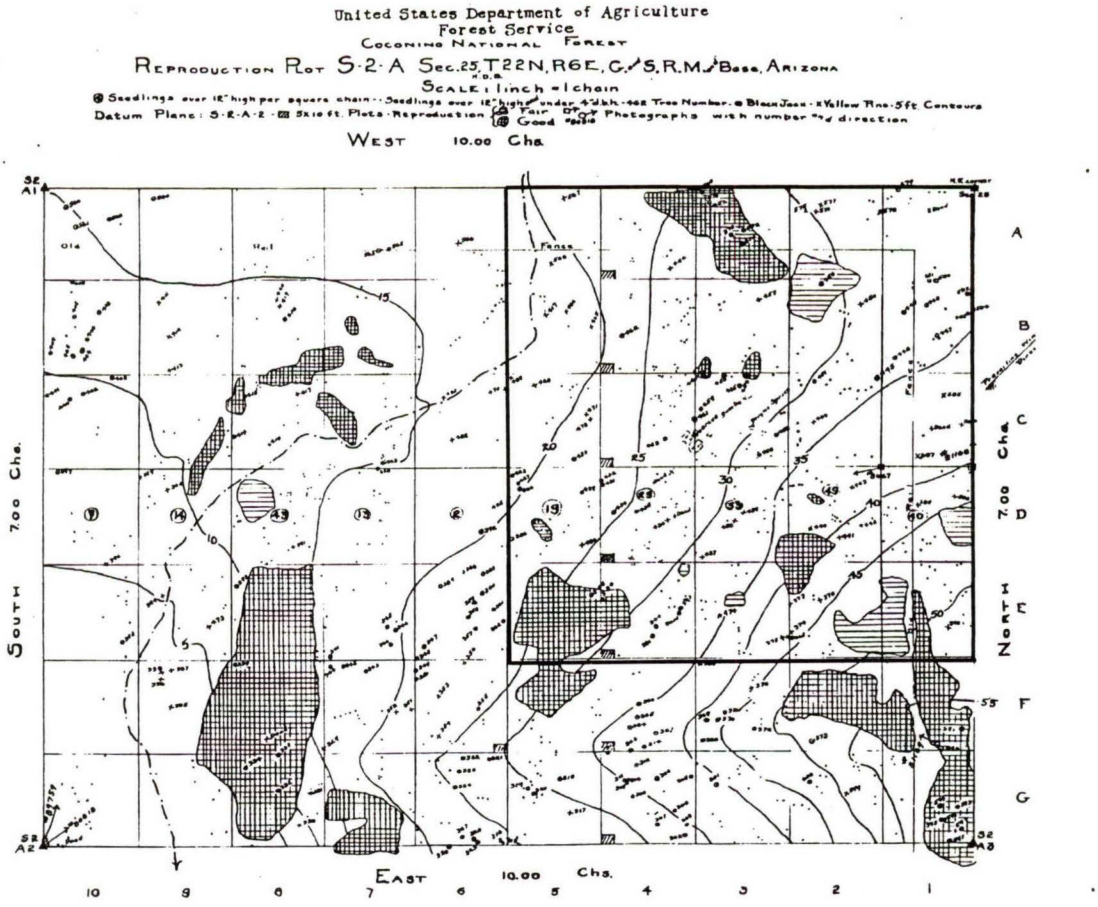
Datum Plane 1½ ch. S. S1 - B2 Contour interval-5ft.

Mapped by S.F. Wilson and M. Westvelt, Sept. 1915

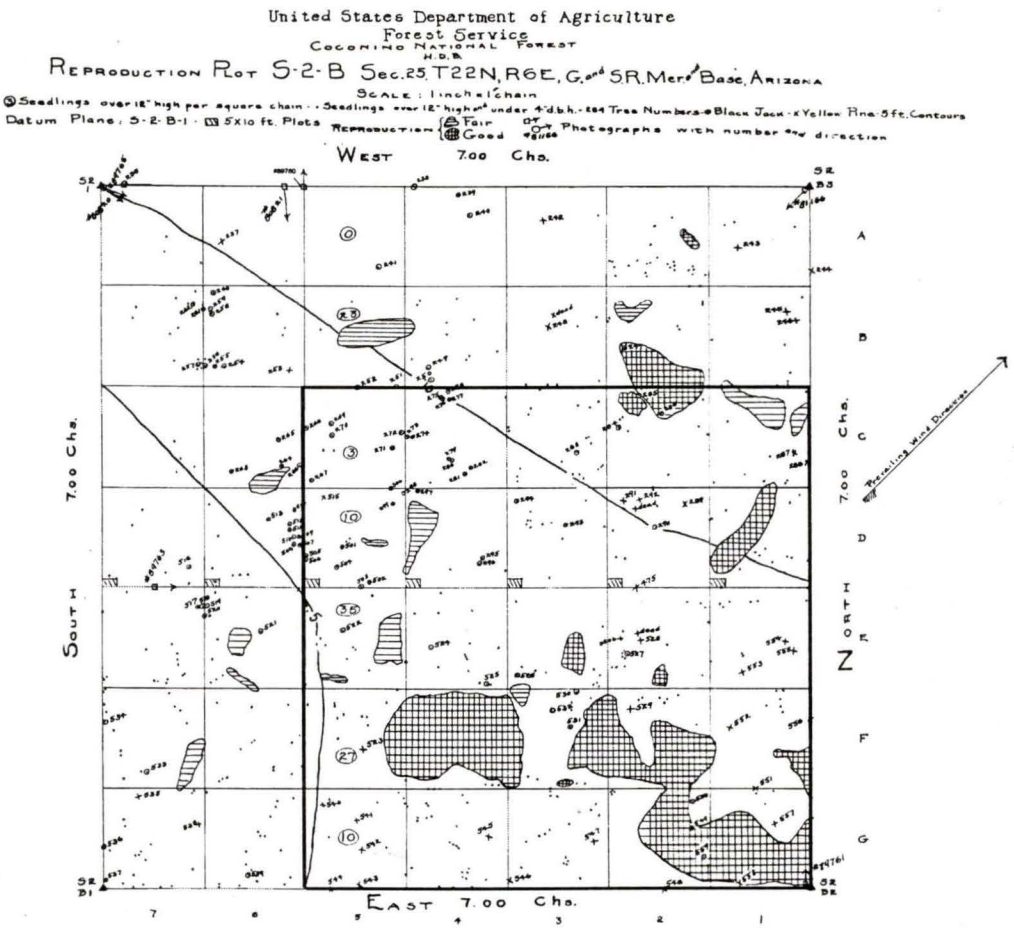
Scale: 1in. = 1ch.



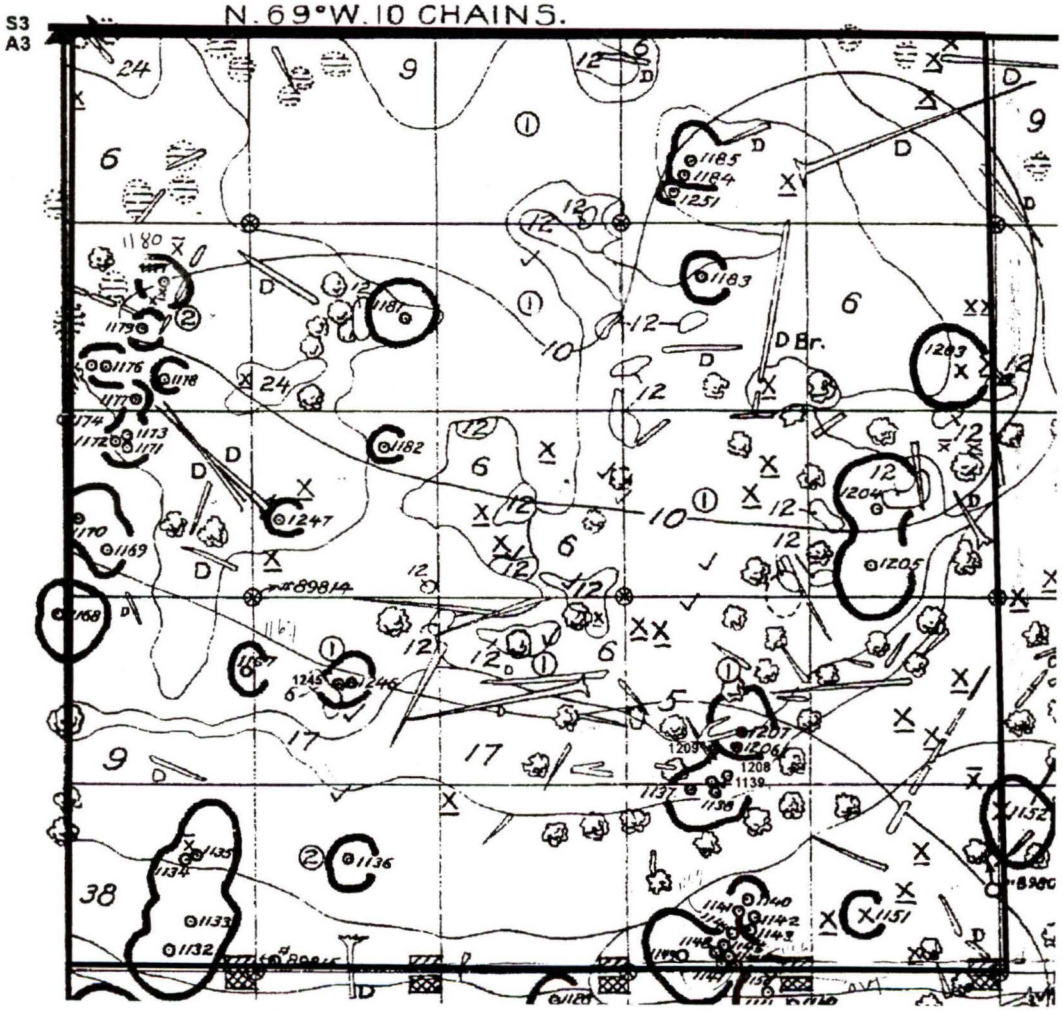
Coconino S1B (COCS1B)



Coconino S2A (COCS2A)


United States Department of Agriculture
Forest Service
Coconino National Forest
Reproduction Plot S-2-B Sec. 25 T22N, R6E, G. and S.R. Mer. Base, Arizona
Scale: 1 inch = 1 chain
Datum Plane: S-2-B-1
Reproduction: Fair, Good
Photographs with number and direction
West 7.00 Chs.
South 7.00 Chs.
North 7.00 Chs.
East 7.00 Chs.
Prevailing Wind Direction

Coconino S2B (COCS2B)



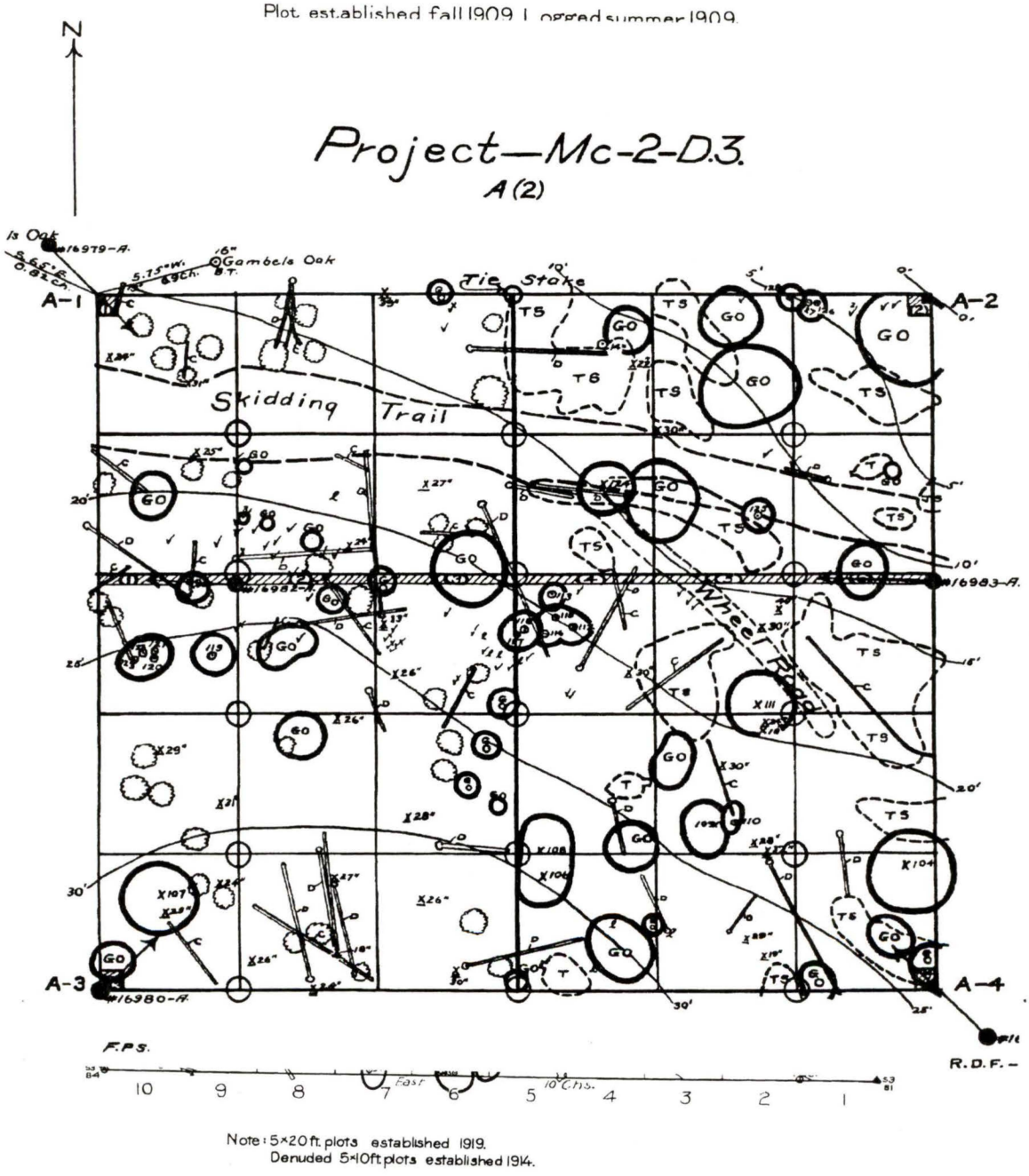
Coconino S3A (COCS3A)

PROJECT Mc-2.

Sample Plot S3-B, Tusayan National Forest.

Location within area S3, Sec. 24, T. 22 N. R. 5 E. G. & S. R. M.

Plot established fall 1909. Logged summer 1909.



Note: 5×20 ft. plots established 1919.
Denuded 5×10 ft. plots established 1914.

Coconino S3B (COCS3B)

PROJECT Mc-2.

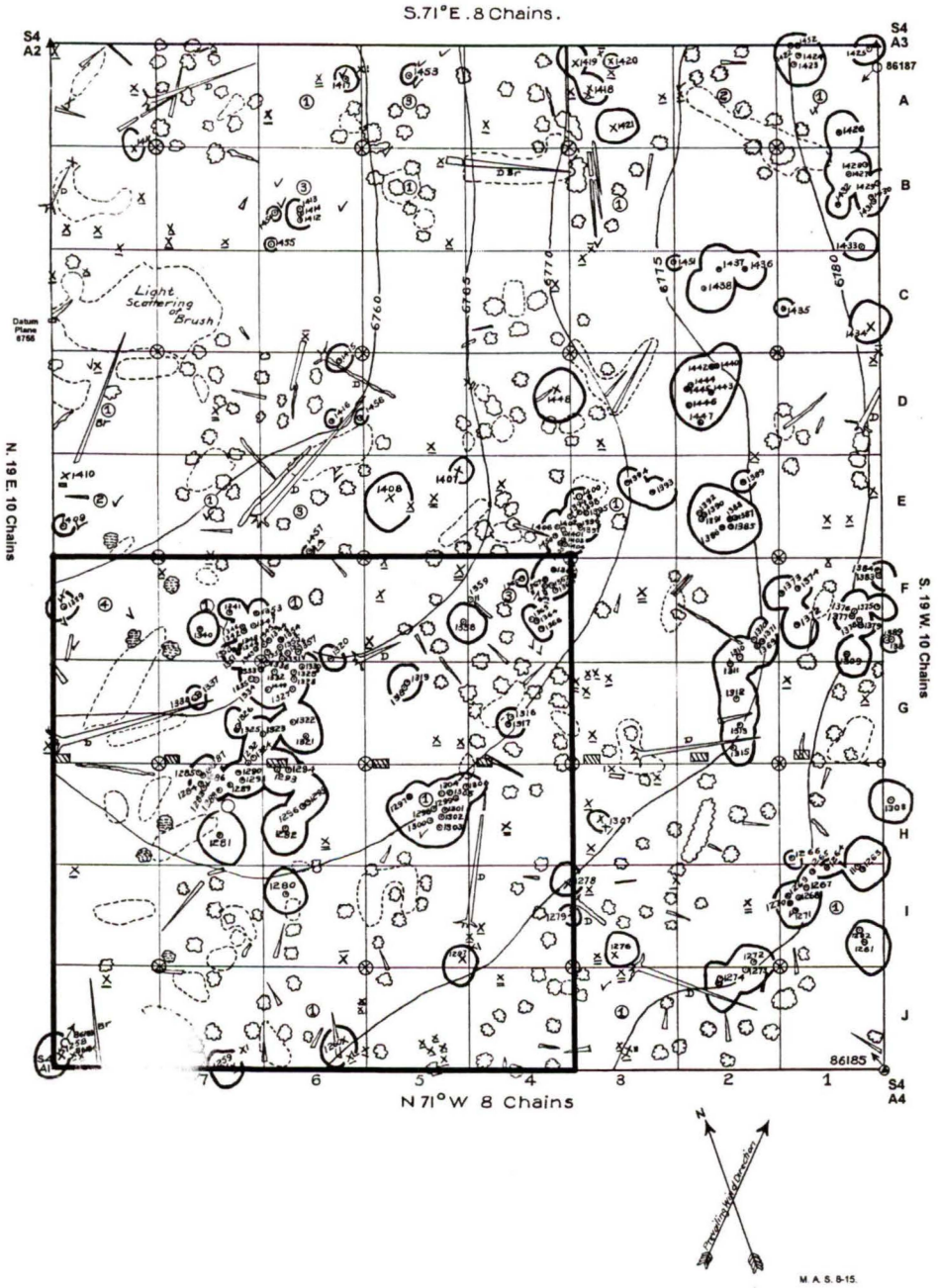
Sample Plot S4-A, Coconino National Forest.

Location NW/4 Sec. 22, T. 22 N., R. 8E. G.&S.R.M.

Plot established fall 1910. Logged fall 1909.

Contour interval 5 ft. Scale 1in.=1chain.

Mapped by E.W. Nelson, November 1914.



Coconino S4A (COCS4A)

PROJECT Mc–2

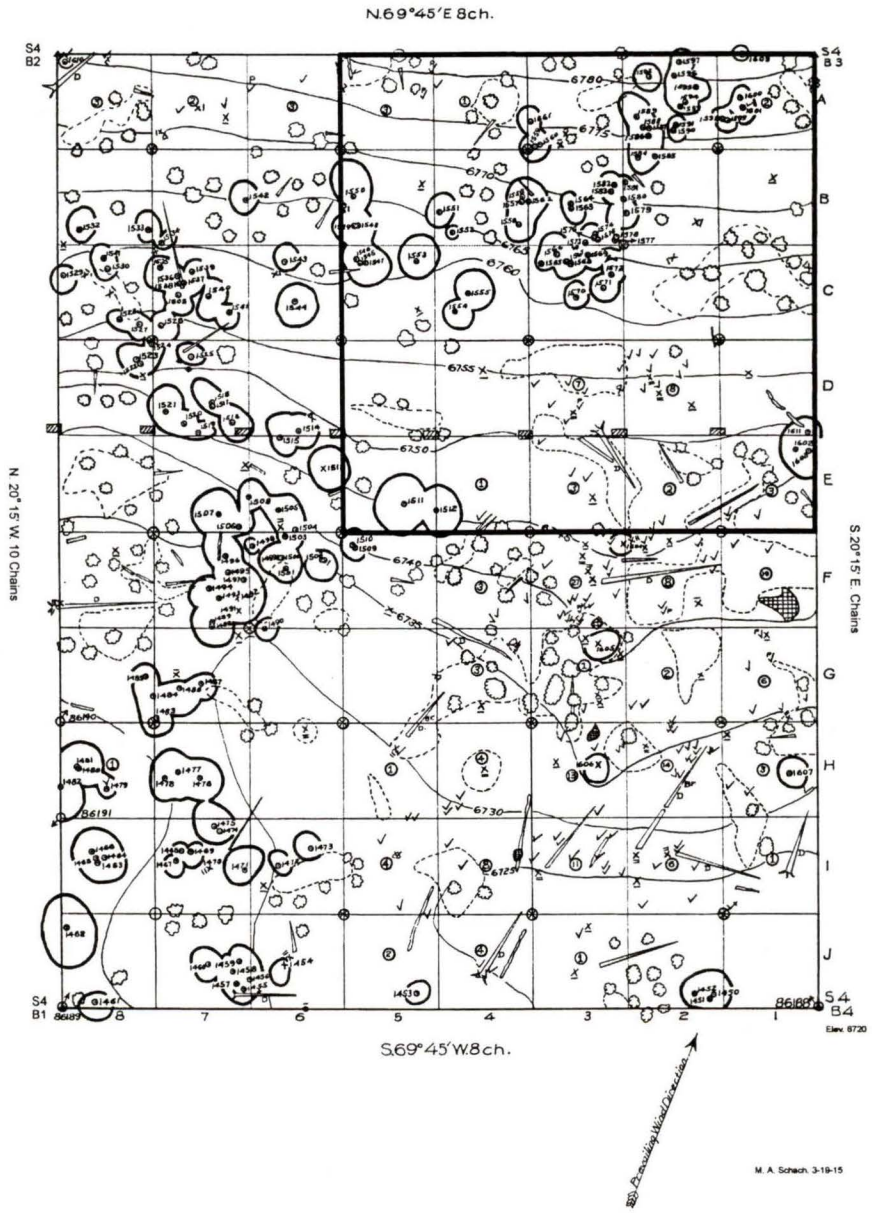
Sample Plot S4-B, Coconino National Forest.

Location: within area S 4, W/2 Sec. 22, T. 22 N., R. 8 E. G. & S. R. M.

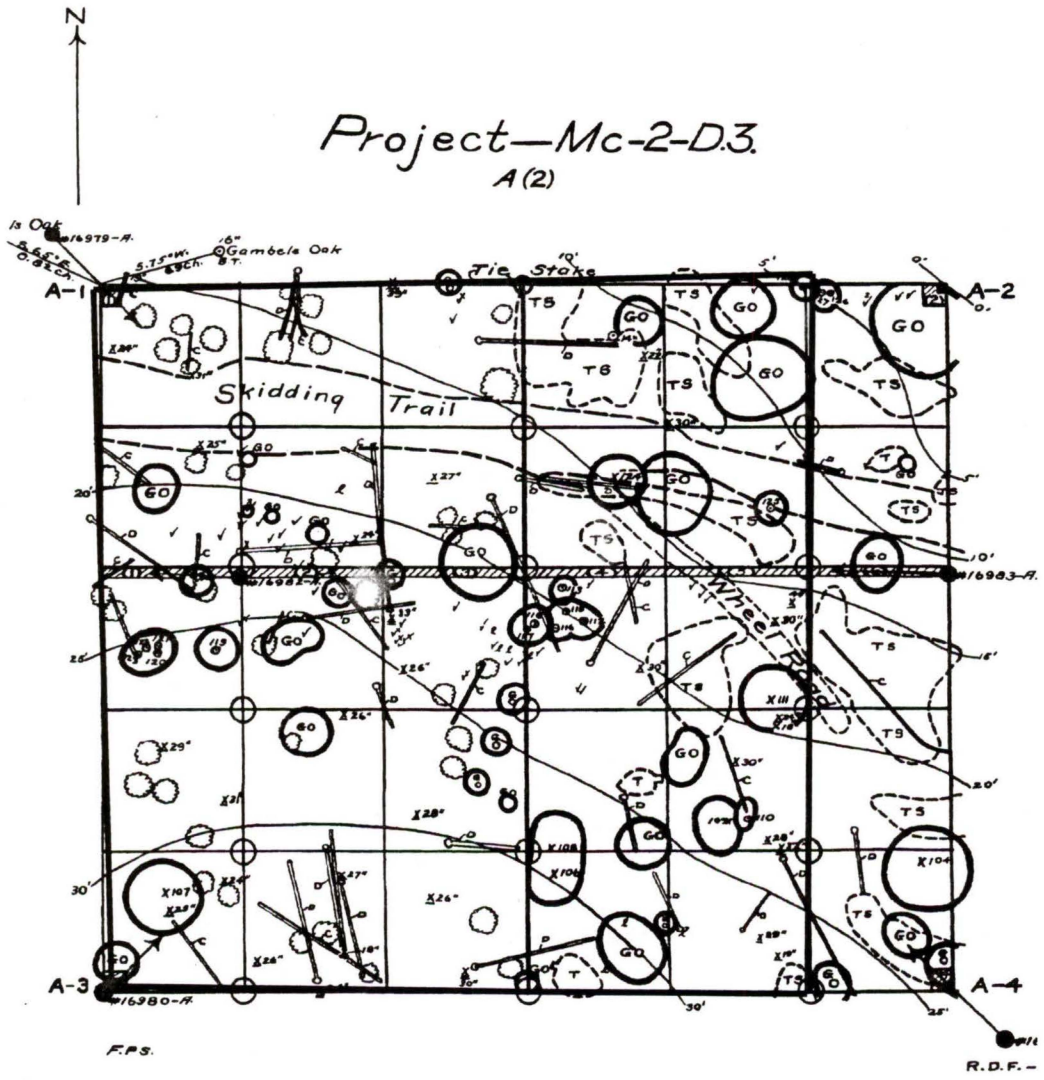
Plot established fall 1909. Logged summer 1909.

Datum Plane S4-B4. Contour interval 5ft. Scale 1in.=1chain.

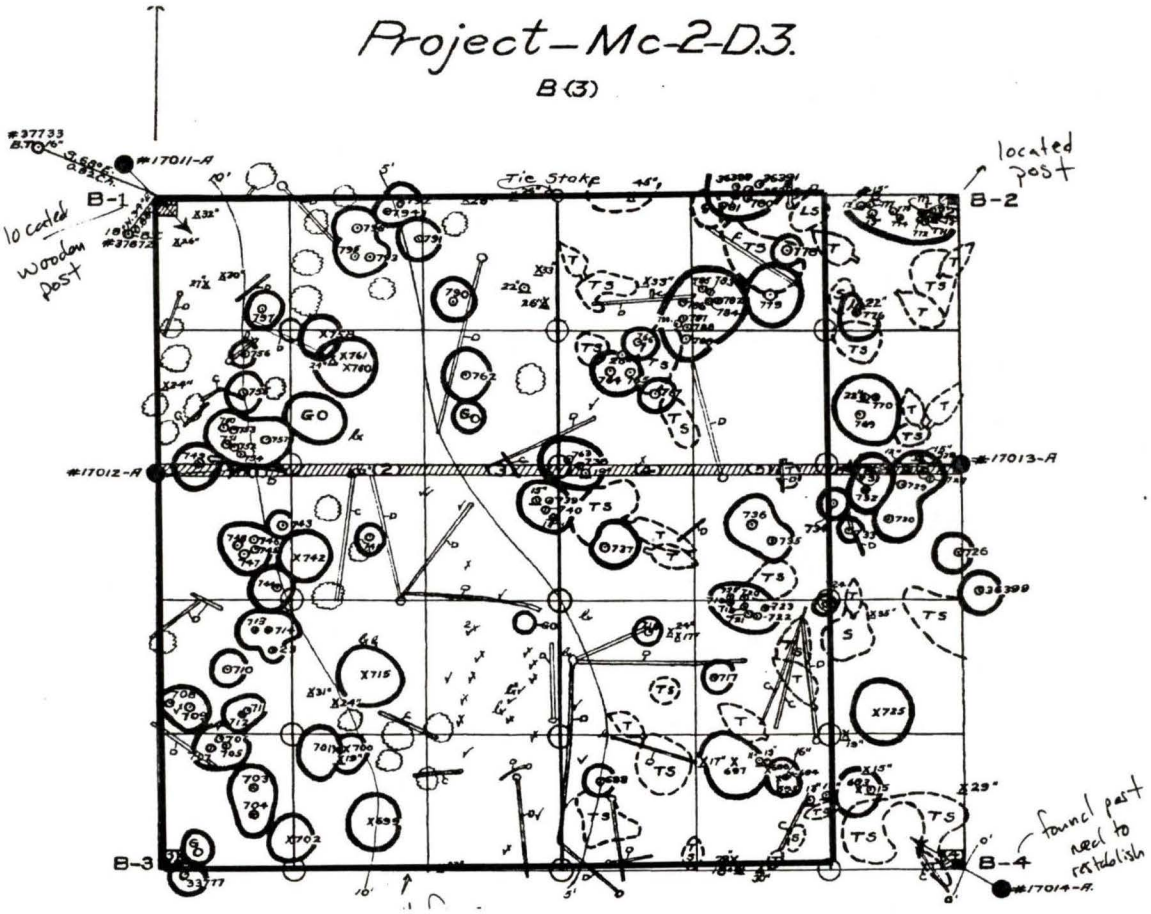
Mapped by E. W. Nelson, October, 1914.



Coconino S4B (COCS4B)



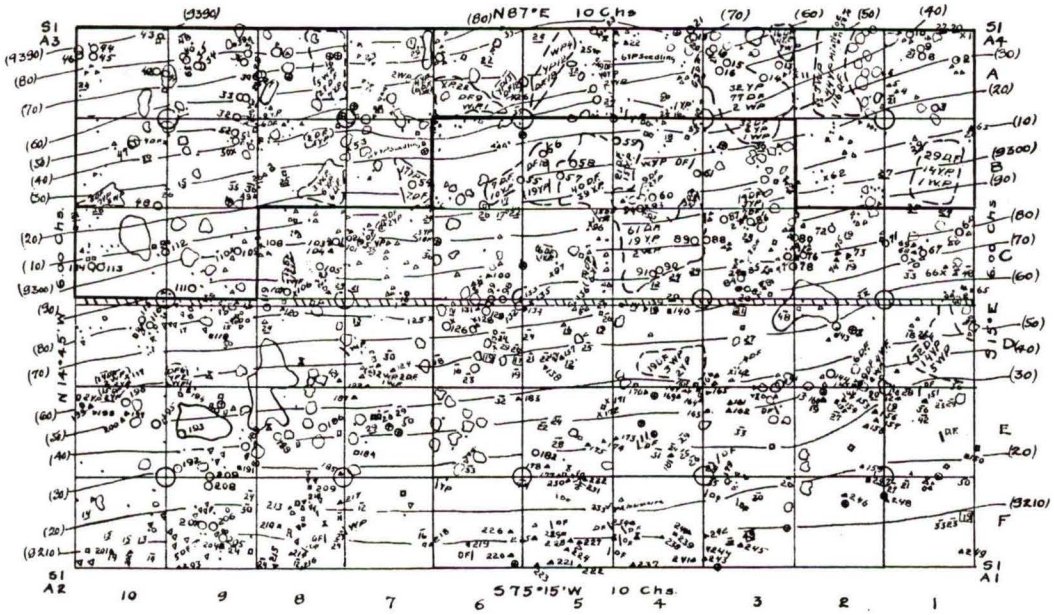
Coconino S5A2 (COCS5A2)



Coconino S5B3 (COCS5B3)

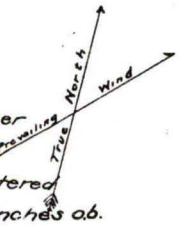
U.S. Department of Agriculture
Forest Service

Permanent Reproduction Sample Plot- S-1-A.
Harry Hermann Timber Sale - 9/16-07. Soccorro Co. Gila N. Forest - N.M.
T. 11 S. R. 18 W. N.M.P.M. - Section 4 - Quarter, North West.
Variation 13°30' E. - Scale : 1 inch = 1 chain - Contour Interval - 10 Ft.
Datum Plane - S-1-A-2.
Mapped by - H.D. Burrall - Traced by A.E. Moss.
Area - 6 Acres.



Legend-

- White Fir
- Douglas Fir
- Mexican White Pine
- Yellow Pine
- Black Jack.
- 16 Tree Number
- Mapping Station
- Brush Piles
- Seedling group with number of each species in each sq.
- Dead Tree
- Windfall with species lettered
- Stumps with diameter inches o.b.



Seedling count strip 5 ft wide. 24 Western Yellow Pine

Seedlings over 12 in. high, under 4 inch. as d.b.h.

- Western Yellow Pine
- Douglas Fir
- Mexican White Pine
- White Fir

23 Douglas Fir
21 Mexican White Pine
43 White Fir

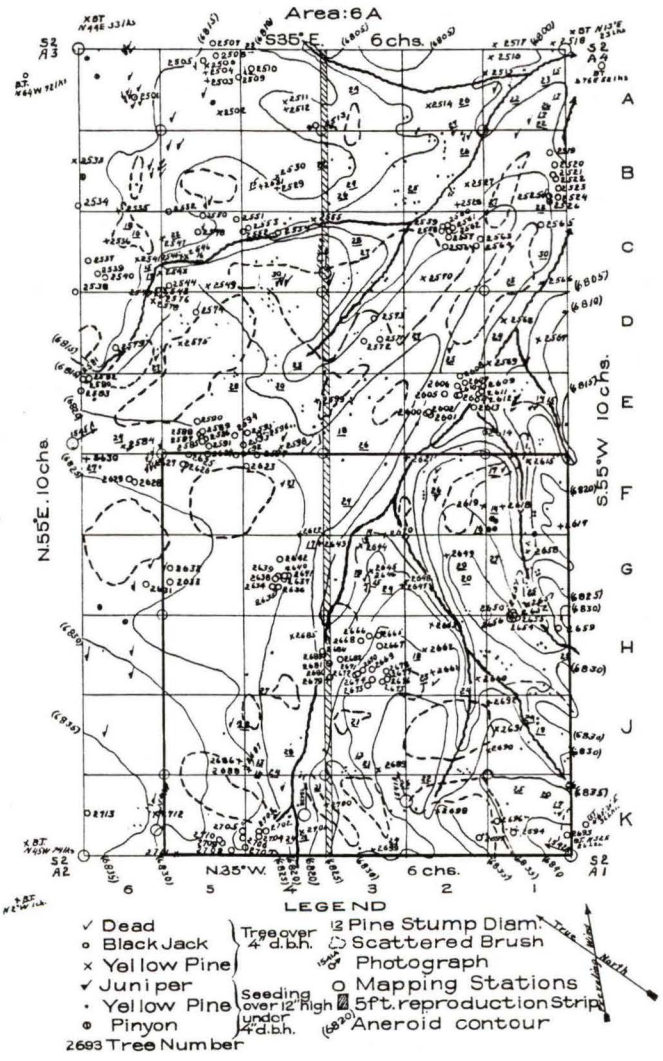
Gila S1A (GILAS1A)

U.S. DEPARTMENT OF AGRICULTURE

FOREST SERVICE

REPRODUCTION SAMPLE PLOT S-2-A

Ramon Land and Lumber Co. July 12, 1909 JEMEZ NATIONAL FOREST, NEW MEXICO
T 19N., R6E., N.M.P.M. Section 22, S.E. Quarter Section 27, N.E Quarter
Scale: 1 inch = 1 chain Contour Intervals 5ft.
Oct. 11, 1911
Mapped by H.D.Burrall
Traced by A. E. Moss

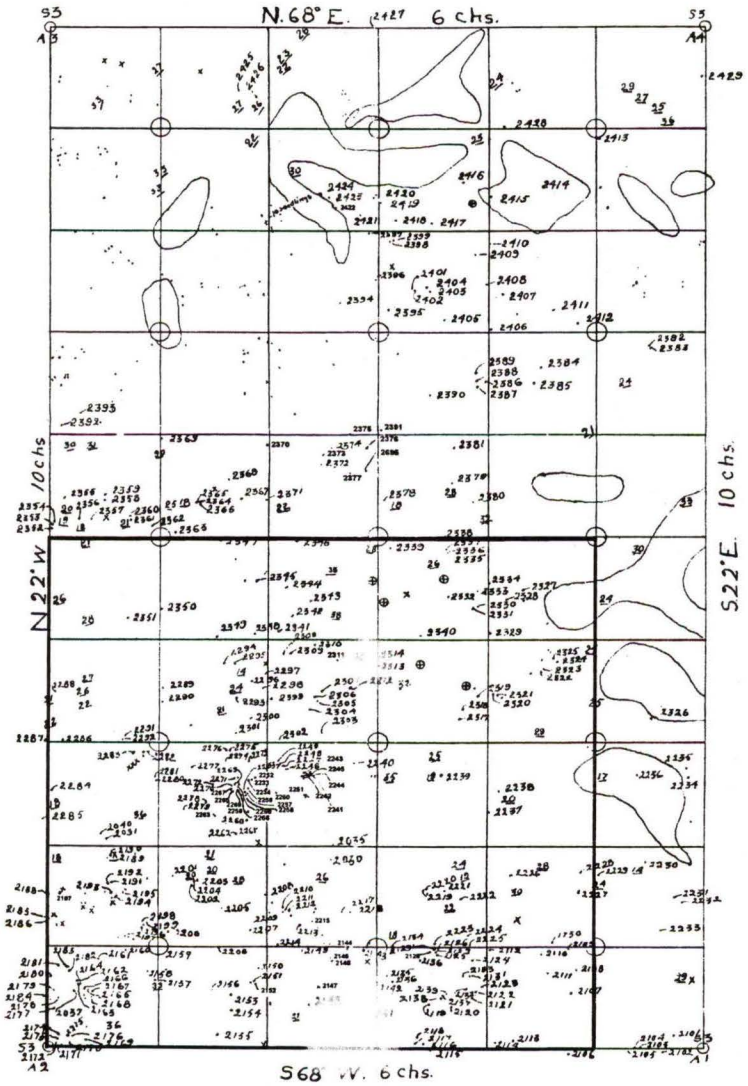


Jemez S2A (JEMS2A)

REPRODUCTION SAMPLE PLOT S-3-A

Sawyer Timber Sale

Jemez National Forest.



LEGEND

- Seedling
- 2395 Tree Number
- 32 Diameter of Stump or Tree marked for cutting
- x Dead Tree
- Scattered Brush
- Piled "
- Mapping Stations

Jemez S3A (JEMS3A)

Appendix II:

Plot descriptions and locations

Note: Earlier plot descriptions from 1909 - 1940 compiled by H. Krausch can be found in the Ft. Valley Historical Archives, USFS Rocky Mountain Research Station, Flagstaff, AZ.

Cibola National Forest, Plot S1A (CIBS1A)

Location

The plot was originally established in 1910 and was remeasured every three to five years up through 1935. The plot is located on the Magdalena Ranger District of the Cibola National Forest in the SE ¼ of Section 11, T5S, R7W. The UTM coordinate for the northwest corner (S1A4) is north 3754789.452 and east 820871.085. The plot is on the Monica Saddle 7.5 minute quadrangle. To reach the plot, travel approximately 10.5 west, from Magdalena, on Highway 60. Turn south onto Highway 52 (FS Road 549) and travel approximately 6.3 miles to FS Road 220. . Turn southwest and continue 8.5 miles on FS Road 220 until the intersection with FS Road 713. At this intersection there is a sign that states "Point of Rocks Canyon". A road, FS Road 220A, takes off to the southeast at this intersection. Follow this road for a short distance to a gate and park. Walk approximately 2.4 miles up Point of Rocks Canyon. The plot extends northeast up the slope from the road.

Current Description

The plot is 6 acres in size. Slopes are 15 – 30% throughout the plot. It contains a wide distribution of size and age groups, predominately blackjacks with some yellow pine. Douglas-fir occurrence is heaviest in the western portion of the plot. There are scattered heavy clumps of ponderosa pine regeneration throughout the plot. Gambel oak regeneration is heaviest in the eastern portion. The soil is exposed, coarse and of volcanic origin.

Original 4x4 inch wooden markers for corners S1A2, S1A3, and S1A4 were located. Most of the original tree tags remain but some of the original tags were replaced at a later time with new numbers. These new numbers are not on the original stem map. The stem map shows ten 5x10 foot understory regeneration plots. These were not located in the field but attempts will be made to locate these during the next visit to the plot.

The common understory species include *Rosa* species, *Viola canadensis*, *Fragaria* species, *Geranium* species, and *Thalictrum fendleri*.

Data Available

A stem map, location map, and remeasurement data exist for this plot. The original tree data (tree number, dbh, height, age group, species, crown information, and tree condition) are on file in Ft Valley Archives. Species lists and brief descriptions of the ten understory regeneration plots are also on file.

Cibola National Forest, Plot S2A (CIBS2A)

Location

The plot was originally established in 1910 and was remeasured every three to five years up through 1935. The plot is located on the Magdalena Ranger District of the Cibola National Forest in the NW ¼ of Section 9, T5S, R7W. The UTM coordinate for the northwest corner (S2A4) is north 3755253.350 and east 817065.866. The plot is on the Monica Saddle 7.5 minute quadrangle. To reach the plot, travel approximately 10.5 west, from Magdalena, on Highway 60. Turn south onto Highway 52 (FS Road 549) and travel approximately 6.3 miles to FS Road 220. Turn southwest and continue 8.5 miles on FS Road 220 until the intersection with FS Road 713. Continue south on FS Road 713 for 1.3 miles. This is the approximate area of the northeast corner of the plot.

Current Description

The plot is 14.4 acres. A drainage passes through the plot from the northeast quarter down through the northwest quarter. The southern edge of the plot is slightly rolling while the northeast corner has a 40 percent slope with a southerly aspect. The average slope for the entire plot is 5 – 10 percent.

The plot contains mostly ponderosa pine with all size classes represented. There are scattered openings throughout the area. Douglas-fir and southwestern white pine are also regenerating near the northeast corner of the plot. Gambel oak occurs on the plot with some larger than 10 inches dbh. The overall crown closure of Gambel oak on the plot is less than 5 percent with the highest concentrations in the northeast corner.

Forest Service Road 713 passes through the east/west through the plot. Another road is located in the southwest quarter of the plot. It begins as FS Road 713 and continues south out of the plot. The stem map shows a wagon road passing through the northern half of the plot. Remains of this road are still visible.

Corner markers were located for corners A1, A3, and A4. Many of the original tree tags remain. The stem map shows twelve 5x10 foot understory regeneration plots. These were not located in the field but attempts will be made to locate these during the next visit to the plot.

Quercus species and grasses occur in the understory.

Data Available

A stem map, location map, and remeasurement data exist for this plot. The original tree data (tree number, dbh, height, age group, species, crown information, and tree condition) are on file in the Ft Valley Archives. Species lists and brief descriptions of the twelve understory regeneration plots are also on file.

Coconino National Forest, Plot S1A (COCS1A)

Location

The plot was established in 1909, mapped in 1915, and was remeasured every three to five years up through 1934. The plot is located on the Peaks Ranger District of the Coconino National Forest, slightly west of the Fort Valley Experimental Station Headquarters, in the NW ¼ of Section 27, T22N, R6E and is on the Humphrey's Peak 7.5 minute series USGS quad. The UTM coordinate for the northwest corner (S1A3) is north 3903007.11 and east 431744.93. The plot can be reached by walking west from the Experimental Station along the wire fence that begins at the fenced experimental plot west of the Station buildings. This fence soon becomes a rail fence. The corners are marked with 1 inch galvanized pipe. The plot can also be reached by traveling west on Forest Service Road 222 (located just north of the turn off for the Experimental Station) for one half mile and then walking south into the plot. The Fort Valley Experimental Station Headquarters is approximately 11 miles northwest of Flagstaff on Highway 180.

Current Description

The plot is 6.4 acres. The southern half of the plot is relatively open and flat with blackjacks, scattered yellow pines, and moderate to heavy patches of pine reproduction. The northern half of the plot slopes uphill. Basalt outcrops are present in the northern end of the plot. Pine regeneration is much heavier in the northern portion of the plot. A rail fence (shown on original stem map) is located just inside the northern edge of the plot and the remains of a wire fence are located along the east edge of the plot. Most of the interior grid corners are marked with 1 inch galvanized pipe. Many of the original 2x2 inch wooden stakes from the original mapping are laying on the ground in the plot.

Most of the plot is relatively undisturbed but the northern portion of the plot has been thinned within the past 20 –25 years. Recent cattle grazing is also evident within the plot.

Eight understory regeneration plots are shown on the stem map. All of these understory plots have been relocated. Some of these plots are still delineated with 1 inch galvanized steel pipe. Plots missing the corner markers were reestablished. Two of the plots, A4 and G4, were mapped in August 1914 and remapped in August 1997.

At present, only one of the original tree tags has been located. The tree no longer exists and the tag was found under many inches of litter and soil at the spot the stem map indicates the tree was located. A metal detector was used to search for tags that may have fallen from trees. Many of the trees adjacent to the plot have tags that appear to be the same age as that of the original tree tag that was found.

The common understory species include *Muhlenbergia montana*, *Cirsium wheeleri*, *Lupinus* species, *Senecio* species, *Houstonia wrightii*, *Erigeron divergens*, *Eriogonum alatum*, *Potentilla crinata*, and *Solidago sparsiflora*.

Data Available

A location map and a stem map exist for this plot. The original 1909 tree data (tree number, dbh, height, age group, species, crown information, and tree condition) and the remeasurement data also exist. A brief written summary of the plot, from 1909, exists. Species lists, from 1914 and 1997, and original descriptions of the eight understory regeneration plots and original maps of plots A4 and G4 are on file. Several photos of the plot are on record.

Coconino National Forest, Plot S1B (COCS1B)

Location

The plot was established in 1909, mapped in 1915, and was remeasured every three to five years up through 1934. The plot is located on the Peaks Ranger District of the Coconino National Forest, south of the Fort Valley Experimental Station Headquarters, in the NE ¼ of the SW ¼ of Section 27, T22N, R6E. The UTM coordinate for the southwest corner (S1B4) is north 3902082.836 and east 431778.530. Plot S1B is on the Humphrey's Peak 7.5 minute series USGS quad. The plot can be reached by taking the dirt road south out of the Experimental Station compound. The plot is exactly one mile from the flagpole located near the entrance to the Station and buildings and is approximately four chains east of the road. The Fort Valley Experimental Station is approximately 11 miles northwest of Flagstaff on Highway 180.

Current Description

The plot is 10 acres. It is very flat and appears to be in an area that may have been an open meadow/park and part of the Fort Valley park itself. The northeast corner is mostly open with only a few trees present. A narrow dry wash is located near and runs parallel with the north edge of the plot. The blackjacks are moderate throughout the plot with heavy patches of pine reproduction mainly in the southeast quarter of the plot. A few open areas with scattered yellow pines are present. The plot is mostly undisturbed but evidence of cattle grazing is noticeable. Many private residences are located to the east of the plot and a foot-trail passes across the northern end of the plot.

Ten understory regeneration plots are shown on the stem map. All but one of these was relocated or reestablished. Two of these plots, F2 and F9, were mapped in August 1914 and remapped in August 1997.

None of the original tree tags were located. Corner posts for corners B2-B4 were located and enough of the original interior grid stakes remain that reestablishing corner B1 would not be difficult.

Common understory species on the plot include *Senecio* species, *Potentilla crinata, Carex* [illegible]*alis, Sitanion hystrix, Muhlenbergia montana, Erigeron* species, *Houstonia wrightii*, and *Achillea millefolium.*

Data Available

A location map and a stem map exist for this plot. The original 1909 tree data (tree number, dbh, height, age group, species, crown information, and tree condition) and the remeasurement data also exist. A brief written summary of the plot, from 1909, exists. Species lists, from 1914 and 1997, and original descriptions of the ten understory regeneration plots and original maps of plots F2 and F9 are on file.

Coconino National Forest, Plot S2A (COCS2A)

Location

The plot was established in 1909 and was remeasured every three to five years up through 1934. The plot is located on the Peaks Ranger District of the Coconino National Forest in the NE ¼ of Section 25, T22N, R6E and is on the Humphrey's Peak 7.5 minute series USGS quad. The UTM coordinate for the northeast plot corner is north 3902788 and east 436253. This plot is on the Ft Valley Experimental Forest. To reach the plot, take Highway 180 north out of Flagstaff to within 0.7 miles of the Snowbowl Road (FS Road 516). Turn east on the faint unmarked dirt road and turn north at the first fork. Follow this road approximately .3 miles to its end. The plot is located directly south and adjacent to the end of the road.

Current Description

The plot is 7 acres and is generally flat but does have a basalt outcrop on the eastern third of the plot. A drainage passes through the plot from north to south. There are moderate to heavy concentrations of blackjacks and only a very few yellow pines are present.

The plot is relatively undisturbed despite its close proximity to Highway 180. The original tree tags have all been removed. Only one of the original corner posts, S2 A4 could be located. This corner post also marks the northeast corner of section 25. The remains of a wire fence are located on the north, east and south boundaries of the plot. Many of the interior 1" galvanized steel interior grid markers are still in place.

Seven understory regeneration plots are shown on the stem map. All of these understory plots have been relocated but, because of discrepancies between the stem map, the original written plot description, and the species lists for the understory plots, only two of the plots could be accurately relocated. Two of these plots, B6 and E6, were mapped in September 1914 and remapped in September 1997.

The common understory species include *Muhlenbergia montana, Carex occidentalis, Lupinus* species, *Festuca arizonica, Sitanion hystrix*, and *Cirsium wheeleri*.

Data Available

A location map and stem map exist for this plot. The original 1909 tree data (tree number, dbh, height, age group, species, crown information, and tree condition) and the remeasurement data also exist. A brief written summary of the plot, from 1909, exits. Species lists, from 1914 and 1997, and original descriptions of the seven understory regeneration plots and original maps of plots B6 and E6 are on file. A few photos of this plot are also on file.

Coconino National Forest, Plot S2B (COCS2B)

Location

This plot was originally established in 1909 and was remeasured every three to five years up through 1939. The plot is located in the NW ¼ of Section 25, T22N, R6E and is on the Humphrey's Peak 7.5 minute USGS quad. The UTM coordinate for the northwest plot corner is north 3902800 and east 435108. The plot is reached by taking Highway 180 north from Flagstaff. Proceed to within approximately 0.4 miles of the Snowbowl Road (FS Road 516) and turn south on a faint unmarked road. Travel approximately 0.1 miles. This road is the western boundary of the plot with Highway 180 being the northern boundary of the plot. The plot is on the Peaks Ranger District of the Coconino National Forest and part of the Ft Valley Experimental Forest.

Current Description

The plot is 4.9 acres in size and is very flat. There is a moderate to heavy concentration of blackjacks and a few yellow pines are present.

The plot is relatively undisturbed considering the proximity to Highway 180 but very few of the original tree tags remain and the plot corner markers could not be found. Highway 180 has destroyed the northern edge of the plot and some additional trees have declined and died with the widening of the highway in 1998. A horse trail from the nearby Ski Lift Lodge passes through the center of the plot, paralleling the highway. Many of the 1inch galvanized steel interior grid markers are still in place.

Seven understory regeneration plots are shown on the stem map. Two of these plots, D4 and D1, were mapped in September 1914. The same two plots were remapped in September 1997.

Common understory species include *Potentilla crinata*, *Carex occidentailis*, *Sitanion hystrix, Achillea millifolium, Lotus wrightii, Muhlenbergia montana*, and *Cirsium wheeleri*.

Data Available

A location map and stem map exist for this plot. The original tree data (tree number, DBH, height, age group, species, crown information, and tree condition) and the remeasurement data also exist. A brief written summary of the plot, from 1909, exists. Species lists, from 1914 and 1997, and original descriptions of the seven understory regeneration plots and original maps of plots D1 and D4 are on file. A few photos of this plot are also on file.

Coconino National Forest, Plot S3A (COCS3A)

Location

This plot was established in 1909, mapped in 1914, and was remeasured every three to five years up through 1954. The plot is located on the Peaks Ranger District of the Coconino National Forest in the SE ¼ of Section 24, T22N, R5E and is on the Wing Mountain 7.5 minute series USGS quad. The UTM coordinate for the northwest corner is north 3903189 and east 426268. The plot is part of the Ft Valley Experimental Forest -- Wing Mountain Unit (Unit 3). To reach the plot, travel north out of Flagstaff on Highway 180 approximately 11 miles to FS Road 222. This road is located just north of the turn-off to the Fort Valley Experimental Station. Travel for approximately 5.2 miles, past Maxwell Spring, on FS Road 222 to FS Road 222A. Take road 222A for approximately one mile. The plot is located just west of the road.

Current Description

The plot is 12 acres and is generally flat with a basalt ridge in the southwest corner. The eastern half of the plot has a moderate to heavy concentration of blackjacks with only a very few yellow pines scattered throughout. The east half of the plot has evidence of extensive thinning of seedling to pole size pines. This plot was part of a thinning experiment. The western half of the plot is much more open and has considerably more yellow pines throughout. This half of the plot appears to be largely undisturbed. Many of the yellow pines have the original tree tags and a considerable number of tree tags have been located at the base of yellow pines and stumps with a metal detector. The majority of the 1inch galvanized pipe interior grid markers are still in place. The remains of a wire fence, down in many places, are located on all four sides of the plot.

Ten understory regeneration plots are shown on the stem map. All of these understory plots have been relocated. Many had the original 1inch galvanized pipes in place. Plots with missing pipes were located using the metal detector. Most of the "missing" pipes were under a couple inches of soil and litter. Two of these plots, E5 and E9, were mapped in September 1914 and remapped in September 1997. The common understory species include *Sitanion hystrix, Carex occidentalis, Lupinus argenteus, Festuca arizonica, Muhlenbergia montana*, and *Achillea millifolium*.

In late summer 2000, wildfire burned through the northeastern portion of the subplot. Tree mortality in the burned area appeared to be 80 - 90% based on initial observations. Additionally, a fireline was bulldozed through the plot during fire suppression efforts. One or two historically established understory plots were likely lost due to the combined effects of fire and suppression activities.

Data Available

A location map and stem map exist for this plot. A written summary of the plot, from 1909, exists. The original 1909 tree data (tree number, dbh, height, age group, species, crown information, and tree condition) and the remeasurement data also exist. Species lists, from 1914 and 1997, and original descriptions of the ten understory regeneration plots and maps of plots E5 and E9, are on file.

Coconino National Forest, Plot S3B (COCS3B)

Location

This plot was established in 1909 and was remeasured every three to five years up through 1954. The plot is located on the Peaks Ranger District of the Coconino National Forest in the NE ¼ of Section 24, T22N, R5E. This plot is part of the Ft Valley Experimental Forest -- Wing Mountain Unit (Unit 3). The UTM coordinate for the northeast plot corner is north 3903636 and east 425848. The plot can be reached by taking Highway 180 north out of Flagstaff approximately 11 miles. Turn west on FS Road 222, located just north of the turn-off to the Fort Valley Experimental Station, and travel approximately 5.2 miles to FS Road 222A. Travel approximately 1.1 miles on FS Road 222A and turn west on FS Road 9001P. The plot is approximately 0.7 miles down this road and south and adjacent to the road. The plot is on the Wing Mountain 7.5 minute series USGS quad.

Current Description

The plot covers 12 acres of land and has a gently rolling topography. The central portion and the southeast corner of the plot have exposed basalt outcrops. Blackjacks dominate the plot with a few yellow pines scattered throughout. There is evidence of thinning since the establishment of the plot. Part of the thinning was a "mistletoe sanitation" cut (ca 1950). There was also a small wildfire to the southwest of the plot. Some of the yellow pines have the original tree tags and tags were found at the bases of yellow pines and stumps using a metal detector. Many of the 1 inch galvanized pipe interior grid markers are in place. The remains of a wire fence still surrounds the plot.

Ten understory regeneration plots are shown on the stem map. Some of these plots were still defined with the original 1inch galvanize pipes while others were relocated and reestablished using a metal detector to locate the buried pipes. The common understory species include *Festuca arizonica*, *Lupinus* species, *Carex occidentalis, Sitanion hystrix*, and *Muhlenbergia montana.*

The fire that burned plot COCS3A also burned this plot. It appeared on initial observation that tree mortality was 100% and understory plots were burned to mineral soil.

Data Available

A location map and stem map exist for this plot. The original 1909 tree data (tree number, dbh, height, age group, species, crown information, and tree condition) and remeasurement data also exist. A brief written summary of the plot, from 1909, is on file. Species lists, from 1914 and 1997, and original descriptions of the ten understory regeneration plots are also on file.

Coconino National Forest S-5 Mormon Lake Plots (COCS5A2 and COCS5B3)

Location

There were 29 plots ranging in size from 0.8 to 3 acres established in this area in 1913. These were remeasured every three to five years up through 1943. The plots are distributed within four distinct units. Units 1-3 have seven plots and Unit 4 has eight plots. Each plot is designated using a letter code followed by the unit number. All plots are located within the Mormon Lake Ranger District in Township 19 N, Range 7 and 8 E, Sections 23, 24, 25, and 30. The majority of the plots are within Section 24. The UTM coordinate for the northwest plot corner of COCS5A2 is north 3873921 and east 445287. The UTM coordinate for the northwest plot corner of COCS5B3 is north 3875206 and east 444056

To reach plots COCS5A2 and COCS5B3, take the Lake Mary Road (FH 3) south for 5.9 miles until FS Road 132 is reached. To reach plot COCS5A2, follow Rd. 132 for 9.4 miles. The plot is located on the south side of the road approximately 0.2 miles off the road.

To reach plot COCS5B3 follow Rd. 132 from the Lake Mary Road turnoff for 8.4 miles unitl FS Rd. 236 is reached. Turn west on Rd. 236 and follow for 0.4 miles until an unmarked road heads north. This road leads to Colter Cabin. Plot COCS5B3 is located just west of the Colter Cabin road, less than 0.1 mile north of the intersection with Rd. 236.

Current Description

Plot COCS5A2 is 3 acres in size and is on relatively flat terrain. Some yellow pine exist and there are many scattered clumps of Gambel oak. Both plots were part of an experiment to determine the effect of different harvesting practices (singles-tree, group selection, etc.) on ponderosa pine growth and regeneration. The original 4x4 post marking the plot corner was found along with several tree tags.

Plot COCS5B3 is generally flat with a small basalt outcrop in the northwest corner. This plot is 3 acres. The east edge of the plot is very open with scattered pines present. Gambel oak is scattered throughout the plot. Some of the original tree tags remain. Corner posts B1 and B2 are present. Pieces of corner posts B3 and B4 are present but need to be reestablished. The remains of an old fence, with only the fence posts remaining, delineates the southern edge of the plot. Seedling tags #254 and 261 are lying near corner post B1. Tag #31509, attached to a seedling pin, is also near post B1. The stem map indicates six seedling count strips located within the plot but no evidence of these was found.

No understory plots were established on either COCS5A2 or COCS5B3. Common understory plants observed included *Robinia neomexicana*, *Rosa woodsii*, *Antennaria* spp., and some grasses.

Data Available

Stem maps exist for all 29 plots as well as an original map showing the locations of all the plots in relation to one another. The original tree data (tree number, dbh, height, age group, species, crown information, and tree condition) exist as does the remeasurement data.

Coconino National Forest, Plots S4A and S4B (COCS4A and COCS4B)

Location

These 8-acre plots were established in 1909. Plot S4A was remeasured every few years through 1934 while plot S4B was remeasured every few years up through 1939. The plots are located on the Peaks Ranger District in the W ½ of Section 22, T22N, R8E and are on the Sunset Crater West 7.5 minute series USGS quad. The UTM coordinate for the southwest plot corner of COCS4A is north 3904169 and east 451070. The UTM coordinate for the northeast plot corner of COCS4B is north 3903469 and east 451176. The plots can be reached by traveling approximately 9 miles northeast out of Flagstaff on Highway 89. The plots are located on the Ft Valley Experimental Forest Unit 4 between the highway and Old Caves Crater.

Current Description

These plots cover 8 acres each. Coconino S4A is on a relatively flat slope whereas Coconino S4B is on rolling terrain. The soils of the area are derived from volcanic cinders. Yellow pine groups dominate the plots with some scattered blackjacks. There are also scattered occurrences of juniper and pinyon pine. The understories are sparse with many patches of exposed back cinders. The area has a few trails used by off-road vehicles. Initially, only one tree tag was located on plot S4A but with a metal detector was used to find several more. Some of the 1-inch galvanized pipes marking the interior grid were located. There has been some harvesting in the area and there is a buried telephone line that bisects the plot. Joe's pile can be found at the base of tree #87.

There are 8 understory plots shown on each original stem map. We relocated these and reestablished the plot corners. Common understory species include *Bouteloua gracilis*, *Fagllugia paradoxa*, *Penstemon* spp., and *Verbascum thapsus*.

Data Available

Written location descriptions and stem maps are available for both plots. A location map also exists for plot S4B. The original 1909 tree data (tree number, dbh, height, age group, species, crown information, and tree condition) and the remeasurement data also exist for these plots.

Gila National Forest, Plot S1A (GILAS1A)

Location

The plot was established in 1912 and was remeasured every three to five years up through 1939. The plot is located in the NE ¼ of Section 4, T1S, R18W on the Grouse Mountain 7.5 minute series USGS quad. The UTM coordinate for the northwest corner (S1A3) is north 3694923.323, and east 712710.319. The plot is reached by traveling east on Highway 159 (FS Road 28), out of Alma, to the town of Mogollon. Continue east out of Mogollon for approximately 6.2 miles. The plot is located on both the north and south sides of the road. The plot is on the Glenwood Ranger District of the Gila National Forest.

Current Description

The plot is 6 acres and the slope is approximately 40 percent from the north end to the south end. The plot contains a mix of sizes with ponderosa pine most predominate in the northwestern portion of the stand. The density and occurrence of Douglas-fir increases in the western portion of the plot. Douglas-fir is the most abundant tree species in the northeast portion of the plot. Understory tree species are ponderosa pine and Douglas fir with some scattered limber pine. Aspen and limber pine occur in the overstory in the southeast corner. The soil is a sandy loam with a large content of cobble size pieces of limestone under a light layer of litter.

The original 4x4 inch corner posts for corners S1A2, S1A3, and S1A4 were located. Many of the original tree tags are still in place.

Roughly one-third of the plot has been removed and replaced by a road and road cut. Due to the steep slope, the road cut on the north side of the road is quite large. An old wagon road, shown on the original location map, is visible directly south of the plot.

The common understory species include *Pyrola* species, *Viola* species, *Pteridium aquilinum*, *Symphoricarpos* species, and *Geranium* species.

Data Available

A location map and stem map exist for this plot. The original 1912 tree data (tree number, dbh, height, age group, species, crown information, and tree condition) and the remeasurement data also exist. A few photos of the plot are on file.

Santa Fe National Forest, Jemez Plots (JEMS2A and JEM?3A)

Location

Originally there were three plots established on what was, at the time, the Jemez National Forest. Plot S1A is located on the Espanola Ranger District of the Santa Fe National Forest in the NE ¼ of section 8, T19N, R6E and is on the Guaje Mountain 7.5 minute series USGS quad. To reach plot S1A, head north Road 501. Road 501 ends right before the University of New Mexico and becomes Diamond Drive. Continue north on Diamond Drive for .95 miles and then turn west on Urban Street for .3 miles. Go north on 46th Street to the end of the road (a cul-de-sac). This is the approximate area of the northwest corner of the plot.

Plot S2A is in the SE ¼ of Section 22 and the NE ¼ of section 27, T19N, R6E and is on the Frijoles 7.5 minute series USGS quad. The UTM coordinate for the northwest corner is north 3968962.897 and east 383796.014. To reach the plot, stay on Diamond Road (501/502) south past a bridge that crosses over Los Alamos Canyon and continue south until reaching Pajarito Road. This is the road that leads to the town of White Rock. From the Diamond - Pajarito intersection, go south on 501 (Pajarito Rd.) to "Tech" road (63/52/5). Travel down road 63/52/5 for 0.2 miles and then turn south on to the transmission line road (before compound fence), continue past a building and parking lot into a two track road. Go 0.2 miles to the head of the canyon and follow into the canyon (called Buey or Ox Canyon) where the plot is located. The plot starts at approximately the first set of transmission line poles.

Plot S3A is in the SE ¼ of Section 2, T18N, R5E and Section 35 of T19N, R5E and is on the Bland 7.5 minute series USGS quad. The UTM coordinate for the southwest corner (S3A2) is north 3974614.770 and east 315887.442. This plot can be reached by traveling west on Road 4 out of Los Alamos to milepost # 47. Go .2 miles past milepost # 47 to the plot. Enter the plot on the south side of the road. The plot is located within Bandelier National Monument.

Current Description

Plot S1A now resides in a residential area with little evidence of the natural stand condition. There is an undisturbed drainage area in the approximate area of the NW corner of the stand but no evidence of tree tags or plot corner markers were found. Large plot trees exist in the yards of the nearby residences.

Plot S2A resides in a gently sloping canyon basin with alluvial washes on both sides. Many of the yellow Ponderosa Pines are still tagged. Ponderosa pine blackjacks, one-seed juniper (Jumo), and two-needle pinyon (Pied) are scattered throughout the area. Along the washes, gambel oak (Quga), currant (Rice), and skunkbush (Rhar) exist. Herbaceous plants include: *Carex* (goephila complex), *Stipa* species, *Poa fendleriana*, (Kopy), *Blepharoneuron tricholepis*, *Bouteloua gracilis*, *Lupinus* species, and *Antennaria parvifolia*.

A portion of the northern corner of plot S2A has been cleared and now has a transmission line running through it (10 to 20 percent of the trees have been removed). The rest of the stand appears relatively undisturbed. Teher has been some downcutting of a samll drainage that runs through the plot. This plot was burned in the Cerro Grande Fire, May 2000. Portions of the plot were completely destroyed by crown fire and other parts were slightly to severely scorched.

Plot S3A sits on a south slope (slope percent varying from 5 to 25 percent) with a drainage on the east and west side of the plot making the plot appear to be sitting on a hummock or ridge. Scattered large ponderosa pines are in the overstory with varying ages of ponderosa pine and some Douglas-fir below. White fir is also present on the site in very small amounts. The east drainage contains some Aspen (up to 15 inches). Gambel oak is scattered throughout the site (mostly in shrub form) with some New Mexico Locust. The northern portion of the overall plot was destroyed by Highway 4. The La Mesa Fire of 1977 burned some trees on the plot and other plot trees were cut along the highway to control the fire (part of the fireline). The Cerro Grande Fire, May 2000, occurred on the northern edge of the plot but did not affect

Data Available

All three plots on the Jemez have individual tree records which include: tree number, dbh, total height, age group (blackjack or yellow pine), species, crown information, and condition of the tree. The individual trees have been remeasured several times through 1934. Stem maps exist for each of the plots as well as written location descriptions of the general plants, seedlings and liter in the sub-plot areas of each plot.

Appendix III:

Example of the reconstruction model

```
* (The following is an R-Base macro designed to calculate presettlement)
*(forest structure in northern Arizona ponderosa pine)

*(Pete Fule, Amy Waltz, Joe Crouse, Dave Huffman)
*(December 2, 1998)

*(Procedure from Camp Navajo, Grand Canyon, & GPNA, AZ, applied to Woolsey plot COCS1A, Fort Valley, AZ)

*(NOTE: inputs, outputs, and all internal calculations are in METRIC units)

*(Inventory year is 1997 --increment through 1996)
*(Exclusion year is 1876 (Dieterich 1976), plot establishment year 1909, plot mapping year 1914)

open s1a

*(Set inventory and fire exclusion dates)
update over set inyr = 1996 where tree# exists
update over set exyr = 1876 where tree# exists

*(Set global inventory and exclusion dates for growth loop functions)
set var iny integer
set var exy integer
set var iny to 1996
set var exy to 1876

set var title text
set var title to DBH calculations
sho var title

*(Computes dbh/dsh from dsh-dbh relationships & bark thickness equations)

*(Use actual dbh/dsh measurement wherever taken in the field)
update over set dbh_x = dbh where dbh exists and dbh gt 0
update over set dsh_x = dsh where dsh exists and dsh gt 0

*(Dsh-dbh regressions from field data set [live trees], Hann 1976 [stumps w/o bark])
set var title to Ponderosa pine
sho var title
update over set dbh_x = (-1.45 + (.94 * dsh)) where species eq PIPO and (dbh fails or dbh eq 0) and cond le 4
*(update over set dbh_x = (-0.46 + (.92 * dsh)) where species eq PIPO and (dbh fails or dbh eq 0) and cond le 4 and
block eq 3)
update over set dbh_x = ((1.8887 + (.9528*(dsh/2.54)))*2.54) where species eq PIPO and (dbh fails or dbh eq 0) and
cond gt 4 and dsh ge 40
update over set dbh_x = ((.5520 + (1.0156*(dsh/2.54)))*2.54) where species eq PIPO and (dbh fails or dbh eq 0) and
cond gt 4 and dsh lt 40
update over set dsh_x = (1.64 + (1.055 * dbh)) where species eq PIPO and (dsh fails or dsh eq 0) and cond le 4
*(update over set dsh_x = (1.21 + (1.077 * dbh)) where species eq PIPO and (dsh fails or dsh eq 0) and cond le 4 and
block eq 3)

set var title to Douglas fir
sho var title
update over set dbh_x = (-1.26 + (.902 * dsh)) where species eq PSME and (dbh fails or dbh eq 0) and cond le 4
update over set dbh_x = (.2223 + ((1.0002*(dsh/2.54)))*2.54) where species eq PSME and (dbh fails or dbh eq 0) and
cond gt 4
update over set dsh_x = (1.514 + (1.104 * dbh)) where species eq PSME and (dsh fails or dsh eq 0) and cond le 4
```

```
set var title to White fir
sho var title
update over set dbh_x = (.109 + (.842 * dsh)) where species eq ABCO  and (dbh fails or dbh eq 0) and cond le 4
update over set dbh_x = ((.4499 + (.9636*(dsh/2.54)))*2.54) where species eq ABCO  and (dbh fails or dbh eq 0) and
cond gt 4
update over set dsh_x = (2.19 + (1.081 * dbh)) where species eq ABCO  and (dsh fails or dsh eq 0) and cond le 4

set var title to Junipers
sho var title
update over set dbh_x = (1.587 + (.736 * dsh)) where species eq JUOS and (dbh fails or dbh eq 0)
update over set dbh_x = (dbh_x/.95) where species eq JUOS and (dbh fails or dbh eq 0) and cond gt 4
update over set dsh_x = (.52 + (1.228 * dbh)) where species eq JUOS and (dsh fails or dsh eq 0)

set var title to Gambel oak
sho var title
update over set dbh_x = (-.615 + (.939 * dsh)) where species eq QUGA  and (dbh fails or dbh eq 0)
update over set dbh_x = (dbh_x/.95) where species eq QUGA  and (dbh fails or dbh eq 0) and cond gt 4
update over set dsh_x = (1.183 + (1.035 * dbh)) where species eq QUGA  and (dsh fails or dsh eq 0)

set var title to Aspen
sho var title
update over set dbh_x = (.469 + (.915 * dsh)) where species eq POTR  and (dbh fails or dbh eq 0)
update over set dbh_x = (dbh_x/.95) where species eq POTR  and (dbh fails or dbh eq 0) and cond gt 4
update over set dsh_x = (.45 + (1.056 * dbh)) where species eq POTR  and (dsh fails or dsh eq 0)

set var title to Pinyons
sho var title
update over set dbh_x = (.95 * dsh) where species eq PIED and (dbh fails or dbh eq 0)
update over set dbh_x = (dbh_x/.95) where species eq PIED and (dbh fails or dbh eq 0) and cond gt 4
update over set dsh_x = (dbh_x/.95) where species eq PIED and (dsh fails or dsh eq 0)

set var title to Spruce note: dead trees use ABCO eqn
sho var title
update over set dbh_x = (.520 + (.875 * dsh)) where species eq PIEN  and (dbh fails or dbh eq 0) and cond le 4
update over set dbh_x = ((.4499 + (.9636 * (dsh/2.54)))*2.54) where species eq PIEN  and (dbh fails or dbh eq 0) and
cond gt 4
update over set dsh_x = (-.553 + (1.142 * dbh)) where species eq PIEN  and (dsh fails or dsh eq 0) and cond le 4

set var title to Set negative diameter values to 0
sho var title
update over set dbh_x = 0 where dbh_x lt 0
update over set dsh_x = 0 where dsh_x lt 0

set var title to DBH calculations complete
sho var title

*(Determination of presettlement status)

set var title text
set var title to Determine presettlement status
sho var title

*(On this plot: 0 = post, 1 = preplot, 2 = preset)

set var title to Initialize presetx equals zero for all trees
sho var title
```

```
update over set preset_x = 0 where tree# exists

set var title to Trees with increment
sho var title
set var a integer
set var b integer
compute a as count tree# from over where cond le 2 and ((in09 exists and in09 gt 0) or (cdate le (exyr+0)))
set var title to Total live trees with increment:
sho var title
sho var a
update over set preset_x = 1 where cond le 2 and ((in09 exists and in09 gt 0) or (cdate le (exyr+0)))
compute a as count tree# from over where cond le 2 and (in09 fails or in09 eq 0) and preset eq 1 and cdate fails
set var title to Total live trees with presettlement flag but no age data or increment:
sho var title
sho var a

set var title to Dead trees and stumps
sho var title
set var title to Dead trees with presettlement field calls:
sho var title
update over set preset_x = 1 where cond ge 3 and preset ge 1
set var title to Stumps greater than 31.8 cm dsh (preplot) or 40 cm dsh (preset) but no field call:
sho var title
update over set preset_x = 1 where cond eq 9 and preset ne 1 and dsh ge 31.8

set var title to Gambel oak
sho var title
update over set preset_x = 1 where species eq QUGA  and dbh_x ge 17

set var title to Junipers
sho var title
update over set preset_x = 1 where species eq JUOS and dbh_x ge 18.6

set var title to Pinyons
sho var title
update over set preset_x = 1 where species eq PIED and dbh_x ge 17

set var title to Aspen
sho var title
update over set preset_x = 1 where species eq POTR and dbh_x ge 25

*(final check for age inconsistencies)
set var title to Check for age data inconsistencies
sho var title
update over set preset_x = 1 where cdate le (exyr+0)
update over set preset_x = 1 where preset ge 1 and cond le 2 and (cdate fails or cdate gt (inyr+0)) and (in09 fails or
in09 eq 0)
update over set preset_x = 0 where cdate gt (exyr+0) and cdate lt (inyr+0)

set var title to Presettlement determination complete
sho var title

set var title to Comparison of field calls with current calls
sho var title
set var title to PIPO 1. field  2. current
sho var title
```

```
compute a as count tree# from over where species eq PIPO and preset eq 1
compute b as count tree# from over where species eq PIPO and preset_x eq 1
sho var a
sho var b
set var title to PSME 1. field  2. current
sho var title
compute a as count tree# from over where species eq PSME and preset eq 1
compute b as count tree# from over where species eq PSME and preset_x eq 1
sho var a
sho var b
set var title to ABCO 1. field  2. current
sho var title
compute a as count tree# from over where species eq ABCO  and preset eq 1
compute b as count tree# from over where species eq ABCO  and preset_x eq 1
sho var a
sho var b
set var title to JUSP 1. field  2. current
sho var title
compute a as count tree# from over where species eq JUOS and preset eq 1
compute b as count tree# from over where species eq JUOS and preset_x eq 1
sho var a
sho var b
set var title to QUGA 1. field  2. current
sho var title
compute a as count tree# from over where species eq QUGA  and preset eq 1
compute b as count tree# from over where species eq QUGA  and preset_x eq 1
sho var a
sho var b
set var title to POTR 1. field  2. current
sho var title
compute a as count tree# from over where species eq POTR and preset eq 1
compute b as count tree# from over where species eq POTR and preset_x eq 1
sho var a
sho var b
set var title to PIED 1. field  2. current
sho var title
compute a as count tree# from over where species eq PIED and preset eq 1
compute b as count tree# from over where species eq PIED and preset_x eq 1
sho var a
sho var b
set var title to PIEN 1. field  2. current
sho var title
compute a as count tree# from over where species eq PIEN and preset eq 1
compute b as count tree# from over where species eq PIEN and preset_x eq 1
sho var a
sho var b

set var title to Check all presettlement calls carefully
sho var title
set var title to Comparison complete
sho var title

set var title to Stump cut dates
sho var title
set var title to Cut 1945
sho var title
```

```
update over set cutdate = 1945 where tree# exists
*(set var title to Assume others cut 1970)
*(sho var title)
*(update over set cutdate = 1950 where species ne PIPO)
set var title to Stump cut dates complete
sho var title

set var title to Decomposition calculations for dead trees
sho var title

set var a integer
set var a to 3
set var pctile real
set var pctile to .50
set var title to Decomposition percentile:
sho var title
sho var pctile

set var title to Initialize death year to inventory year
sho var title
update over set dtyr = inyr where tree# exists
set var a to .a + 1
set var title to Condition class:
sho var title
sho var a
update over set dtyr = (inyr + (((log(.pctile))-(log(1)))/(log(1.2)))) where cond eq 4
set var a to .a + 1
sho var title
sho var a
update over set dtyr = (inyr + (((log(.pctile))-(log(1)))/(log(1.2))) + (((log(.pctile))-(log(1)))/(log(1.15)))) where cond eq
5
set var a to .a + 1
sho var title
sho var a
update over set dtyr = (inyr + (((log(.pctile))-(log(1)))/(log(1.2))) + (((log(.pctile))-(log(1)))/(log(1.15))) +
(((log(.pctile))-(log(1)))/(log(1+(1/(2*(dbh_x/2.54))))))) where cond eq 6
set var a to .a + 1
sho var title
sho var a
update over set dtyr = (inyr + (((log(.pctile))-(log(1)))/(log(1.2))) + (((log(.pctile))-(log(1)))/(log(1.15))) +
(2*(((log(.pctile))-(log(1)))/(log(1+(1/(2*(dbh_x/2.54))))))) where cond eq 7
set var a to .a + 1
sho var title
sho var a
update over set dtyr = (inyr + (((log(.pctile))-(log(1)))/(log(1+(1/(2*(dbh_x/2.54))))))) where cond eq 8
set var a to .a + 1
sho var title
sho var a
update over set dtyr = cutdate where cond eq 9

set variable title to Decomposition calculations complete
sho var title

set var title to Presettlement calculations
sho var title
```

```
set var a integer
compute a as count tree# from over where preset_x eq 0
set var title to Postsettlement trees:
sho var title
sho var a
update over set dshib_pr = 0 where preset_x eq 0
update over set dbh_pr = 0 where preset_x eq 0

set var title to Ponderosa pine
sho var title

'set var a integer
compute a as count tree# from over where species eq PIPO and preset_x eq 1 and in09 exists and in09 gt 0
set var title to Presettlement trees with increment:
sho var title
sho var a
*(update over set dshib_pr = ((((0.9344*(dsh_x/2.54))-1.1923)*2.54)-(2*in09)) where species eq PIPO and preset_x eq
0 and in09 exists and in09 gt 0)
*(update over set dbh_pr = ((.5520+(1.0156*(dshib_pr/2.54)))*2.54) where species eq PIPO and preset_x eq 0 and in09
exists and in09 gt 0)
update over set dshib_pr = ((((0.9498*(dsh_x/2.54))-1.1217)*2.54)-(2*in09)) where species eq PIPO and preset_x eq 1
and in09 exists and in09 gt 0
*(use blackjack dshib-dbhob eqn. from Hann for smaller trees in exclusion year)
update over set dbh_pr = ((.5520+(1.0156*(dshib_pr/2.54)))*2.54) where species eq PIPO and preset_x eq 1 and in09
exists and in09 gt 0 and dshib_pr lt 40
update over set dbh_pr = ((1.8887+(.9528*(dshib_pr/2.54)))*2.54) where species eq PIPO and preset_x eq 1 and in09
exists and in09 gt 0 and dshib_pr ge 40

set var a integer
compute a as count tree# from over where species eq PIPO and preset_x eq 1 and (in09 fails or in09 eq 0)
set var title to Presettlement trees without increment
sho var title
sho var a
*(MBAI eqn from PIPO GRCA-EB data, 1/98, n = 315, r2 = .45, residuals +/-)
update over set dbh_pr = (sqrt((dbh_x*dbh_x)-(((-.00034076+(.00003085*dbh_x))*(dtyr-exyr))/.00007854))) where
species eq PIPO and preset_x eq 1 and (in09 fails or in09 eq 0)
*(set lower end of MBAI eqn with first derivative)
update over set minbai = ((0.5*sqrt((dbh_x*dbh_x)-(((-.00034076*(dtyr-exyr))+(0.00003085*(dtyr-
exyr)*dbh_x))/0.00007854)))*((2*dbh_x)-(0.00003085*(dtyr-exyr)/0.00007854))) where species eq PIPO
update over set minbai = 0 where minbai fails and species eq PIPO
update over set dbh_pr = 0 where species eq PIPO and preset_x eq 1 and (in09 fails or in09 eq 0) and minbai le .1

set var title to White fir
sho var title

set var a integer
compute a as count tree# from over where species eq ABCO  and preset_x eq 1 and in09 exists and in09 gt 0
set var title to Presettlement trees with increment:
sho var title
sho var a
update over set dshib_pr = ((((0.9498*(dsh_x/2.54))-1.1217)*2.54)-(2*in09)) where species eq ABCO  and preset_x eq
1 and in09 exists and in09 gt 0
update over set dbh_pr = ((1.8887+(.9528*(dshib_pr/2.54)))*2.54) where species eq ABCO  and preset_x eq 1 and in09
exists and in09 gt 0

set var a integer
```

```
compute a as count tree# from over where species eq ABCO  and preset_x eq 1 and (in09 fails or in09 eq 0)
set var title to Presettlement trees without increment
sho var title
sho var a
*(MBAI eqn from ABCO GRCA-EB data, 1/98, n = 27, r2 = .90)
update over set dbh_pr = (sqrt((dbh_x*dbh_x)-(((-.00187817+(.00006535*dbh_x))*(dtyr-exyr))/.00007854))) where
species eq ABCO  and preset_x eq 1 and (in09 fails or in09 eq 0)
update over set minbai = ((0.5*sqrt((dbh_x*dbh_x)-(((-.00187817*(dtyr-exyr))+(0.00006535*(dtyr-
exyr)*dbh_x))/0.00007854)))*((2*dbh_x)-(0.00006535*(dtyr-exyr)/0.00007854))) where species eq ABCO
update over set minbai = 0 where minbai fails and species eq ABCO
update over set dbh_pr = 0 where species eq ABCO and preset_x eq 1 and (in09 fails or in09 eq 0) and minbai le .1

set var title to Douglas fir
sho var title

set var a integer
compute a as count tree# from over where species eq PSME  and preset_x eq 1 and in09 exists and in09 gt 0
set var title to Presettlement trees with increment:
sho var title
sho var a
update over set dshib_pr = (((((0.9498*(dsh_x/2.54))-1.1217)*2.54)-(2*in09)) where species eq PSME  and preset_x eq
1 and in09 exists and in09 gt 0
update over set dbh_pr = ((1.8887+(.9528*(dshib_pr/2.54)))*2.54) where species eq PSME  and preset_x eq 1 and in09
exists and in09 gt 0

set var a integer
compute a as count tree# from over where species eq PSME  and preset_x eq 1 and (in09 fails or in09 eq 0)
set var title to Presettlement trees without increment
sho var title
sho var a
*(MBAI eqn from PSME GRCA-EB data, 1/98, n = 9, r2 = .64)
update over set dbh_pr = (sqrt((dbh_x*dbh_x)-(((-.00163039+(.00005851*dbh_x))*(dtyr-exyr))/.00007854))) where
species eq PSME  and preset_x eq 1 and (in09 fails or in09 eq 0)
update over set minbai = ((0.5*sqrt((dbh_x*dbh_x)-(((-.00163039*(dtyr-exyr))+(0.00005851*(dtyr-
exyr)*dbh_x))/0.00007854)))*((2*dbh_x)-(0.00005851*(dtyr-exyr)/0.00007854))) where species eq PSME
update over set minbai = 0 where minbai fails and species eq PSME
update over set dbh_pr = 0 where species eq PSME and preset_x eq 1 and (in09 fails or in09 eq 0) and minbai le .1

set var title to Aspen
sho var title

set var a integer
compute a as count tree# from over where species eq POTR  and preset_x eq 1 and in09 exists and in09 gt 0
set var title to Presettlement trees with increment:
sho var title
sho var a
update over set dshib_pr = (((((0.9498*(dsh_x/2.54))-1.1217)*2.54)-(2*in09)) where species eq POTR  and preset_x eq
1 and in09 exists and in09 gt 0
update over set dbh_pr = ((1.8887+(.9528*(dshib_pr/2.54)))*2.54) where species eq POTR  and preset_x eq 1 and in09
exists and in09 gt 0

set var a integer
compute a as count tree# from over where species eq POTR  and preset_x eq 1 and (in09 fails or in09 eq 0)
set var title to Presettlement trees without increment
sho var title
sho var a
```

```
*(MBAI eqn from POTR GRCA-EB data, 1/98, n = 22, r2 = .79)
update over set dbh_pr = (sqrt((dbh_x*dbh_x)-(((-.00025638+(.00002619*dbh_x))*(dtyr-exyr))/.00007854))) where
species eq POTR  and preset_x eq 1 and (in09 fails or in09 eq 0)
update over set minbai = ((0.5*sqrt((dbh_x*dbh_x)-(((-.00025638*(dtyr-exyr))+(0.00002619*(dtyr-
exyr)*dbh_x))/0.00007854)))*((2*dbh_x)-(0.00002619*(dtyr-exyr)/0.00007854))) where species eq POTR
update over set minbai = 0 where minbai fails and species eq POTR
update over set dbh_pr = 0 where species eq POTR and preset_x eq 1 and (in09 fails or in09 eq 0) and minbai le .1

set var title to Spruce: current default ABCO BAI eqn
sho var title

set var a integer
compute a as count tree# from over where species eq PIEN  and preset_x eq 1 and in09 exists and in09 gt 0
set var title to Presettlement trees with increment:
sho var title
sho var a
update over set dshib_pr = ((((0.9498*(dsh_x/2.54))-1.1217)*2.54)-(2*in09)) where species eq PIEN  and preset_x eq 1
and in09 exists and in09 gt 0
update over set dbh_pr = ((1.8887+(.9528*(dshib_pr/2.54)))*2.54) where species eq PIEN  and preset_x eq 1 and in09
exists and in09 gt 0

set var a integer
compute a as count tree# from over where species eq PIEN  and preset_x eq 1 and (in09 fails or in09 eq 0)
set var title to Presettlement trees without increment
sho var title
sho var a
*(MBAI eqn from ABCO GRCA-EB data, 1/98, n = 27, r2 = .90)
update over set dbh_pr = (sqrt((dbh_x*dbh_x)-(((-.00187817+(.00006535*dbh_x))*(dtyr-exyr))/.00007854))) where
species eq PIEN  and preset_x eq 1 and (in09 fails or in09 eq 0)
update over set minbai = ((0.5*sqrt((dbh_x*dbh_x)-(((-.00187817*(dtyr-exyr))+(0.00006535*(dtyr-
exyr)*dbh_x))/0.00007854)))*((2*dbh_x)-(0.00006535*(dtyr-exyr)/0.00007854))) where species eq PIEN
update over set minbai = 0 where minbai fails and species eq PIEN
update over set dbh_pr = 0 where species eq PIEN and preset_x eq 1 and (in09 fails or in09 eq 0) and minbai le .1

set var title to Gambel oak calculations
sho var title
set var notrees text
set var notrees to No trees found

set var title to Oaks: presettlement with increment
sho var title

*(for presettlement oaks w/ increment, calculate dshib_pr and dbh_pr)
update over set dshib_pr = ((.95*dsh_x)-(2*in09)) where species eq QUGA and preset_x eq 1 and in09 exists and in09
gt 0 and dsh exists
update over set dshib_pr = ((.95*(1.05*dbh))-(2*in09)) where species eq QUGA and preset_x eq 1 and in09 exists and
in09 gt 0 and dsh fails
update over set dbh_pr = (((dshib_pr/.95)*.953)-.713) where species eq QUGA  and preset_x eq 1 and in09 exists and
in09 gt 0

compute a as count tree# from over where species eq QUGA  and preset_x eq 1 and (in09 fails or in09 eq 0)
set var title to Presettlement trees without increment
sho var title
sho var a
*(MBAI eqn from QUGA GRCA-EB data, 1/98, n = 75, r2 = .81)
```

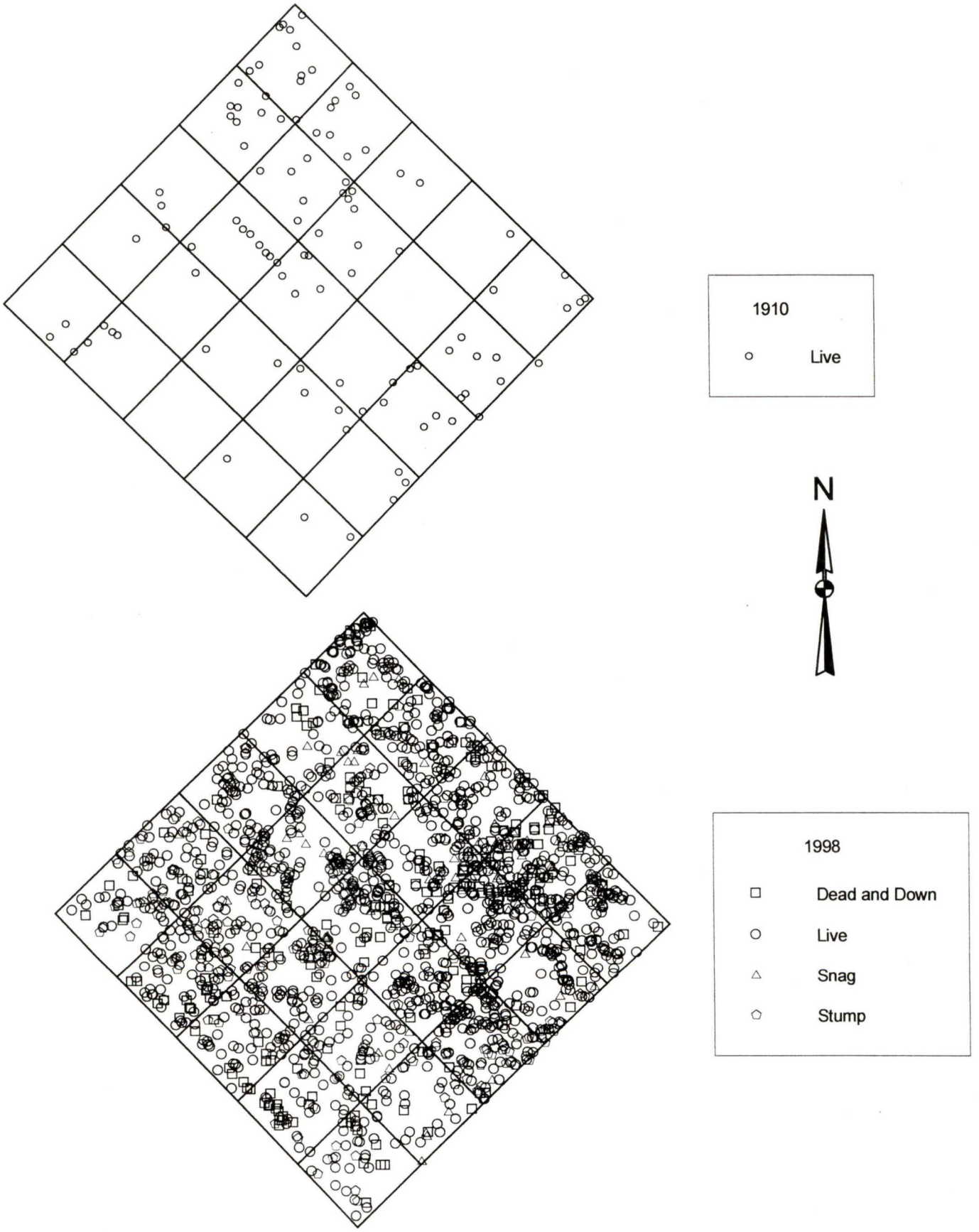
```
update over set dbh_pr = (sqrt((dbh_x*dbh_x)-(((-.00014178+(.00001983*dbh_x))*(dtyr-exyr))/.00007854))) where
species eq QUGA  and preset_x eq 1 and (in09 fails or in09 eq 0)
update over set minbai = ((0.5*sqrt((dbh_x*dbh_x)-(((-.00014178*(dtyr-exyr))+(0.00001983*(dtyr-
exyr)*dbh_x))/0.00007854)))*((2*dbh_x)-(0.00001983*(dtyr-exyr)/0.00007854))) where species eq QUGA
update over set minbai = 0 where minbai fails and species eq QUGA
update over set dbh_pr = 0 where species eq QUGA and preset_x eq 1 and (in09 fails or in09 eq 0) and minbai le .1

*(original program QUGA growth routine:)
*(for presettlement oaks w/o increment, calculate dbh_pr iteratively using ECOSIM eqn.)
*(set var tstcnt integer)
*(compute tstcnt as count tree# from over where species eq QUGA  and preset_x eq 1 and (in09 fails or in09 eq 0))

*(if tstcnt gt 0 then)

*( set var modelyr integer)
*( set var modelyr to .iny)
*( set var title to Oak model year:)
*( update over set dbh_pr = dbh_x where species eq QUGA  and preset_x eq 1 and (in09 fails or in09 eq 0))
*(   while modelyr gt .exy then)

*(       sho var title)
*(       sho var modelyr)
*(       update over set dbh_pr = (dbh_pr-((.0625-(.000382*(dbh_pr/2.54)))*2.54)) where species eq QUGA  and
preset_x eq 1 and (in09 fails or in09 eq 0) and dtyr ge .modelyr)
*(       set var modelyr to (.modelyr-1))

*(   endwhile)

*(else)

*(   sho var notrees)

*(endif)

set var title to Pinyon: presettlement with increment
sho var title

*(for presettlement pinyons w/ increment, calculate dshib_pr and dbh_pr)
update over set dshib_pr = ((.95*dsh_x)-(2*in09)) where species eq PIED  and preset_x eq 1 and in09 exists and in09
gt 0
update over set dbh_pr = (((dshib_pr/.95)*.953)-.713) where species eq PIED  and preset_x eq 1 and in09 exists and
in09 gt 0

set var title to Pinyons: presettlement without increment
sho var title

*(for presettlement pinyons w/o increment, calculate dbh_pr iteratively using ECOSIM eqn.)
set var tstcnt integer
compute tstcnt as count tree# from over where species eq PIED and preset_x eq 1 and (in09 fails or in09 eq 0)
*(set var tstcnt to 0)

if tstcnt gt 0 then

 set var modelyr integer
 set var modelyr to .iny
 set var title to Pinyon model year:
```

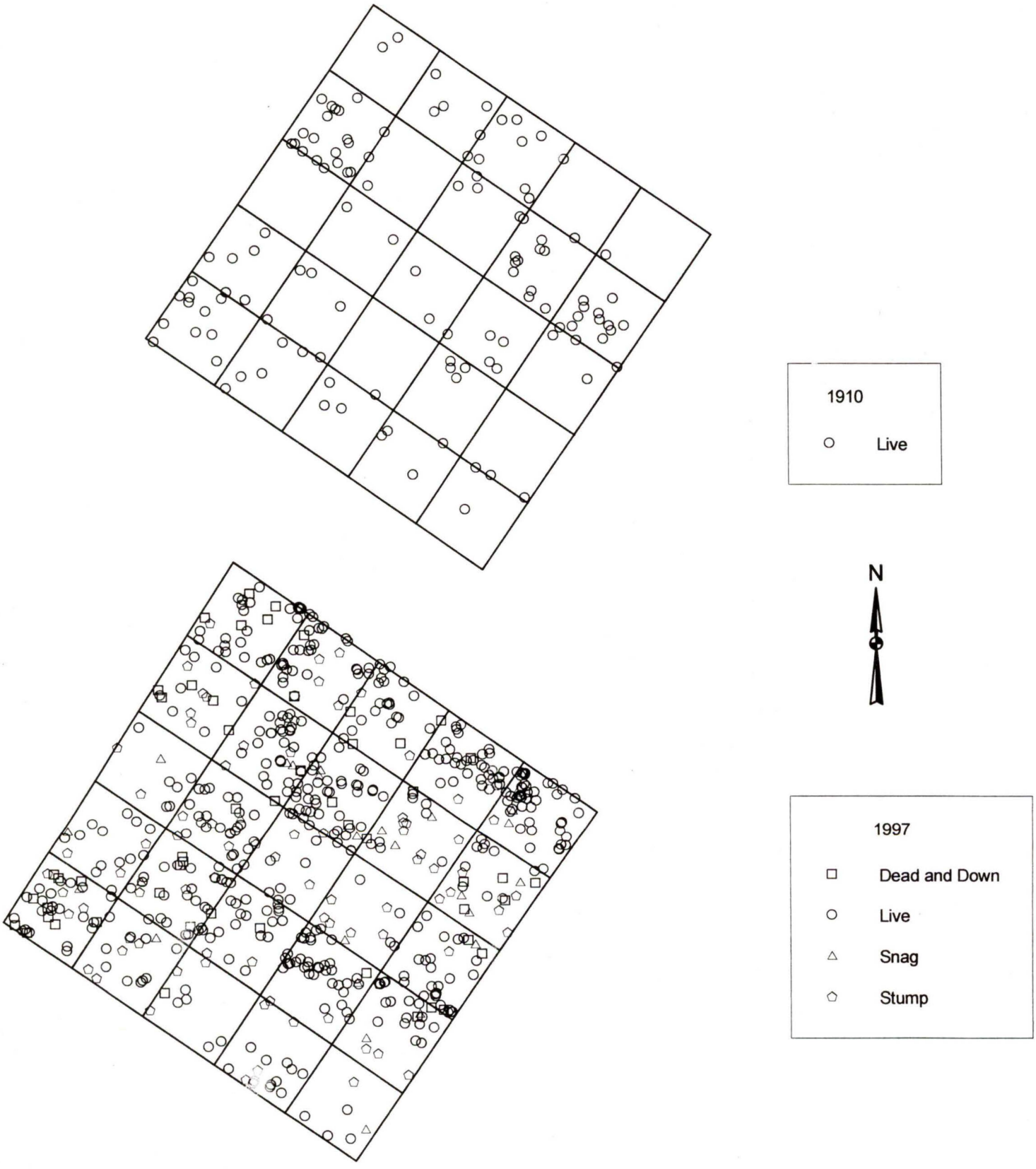
```
update over set dbh_pr = dbh_x where species eq PIED  and preset_x eq 1 and (in09 fails or in09 eq 0)
  while modelyr gt .exy then

      sho var title
      sho var modelyr
      update over set dbh_pr = (dbh_pr-((.0646-(.001077*(dbh_pr/2.54)))*2.54)) where species eq PIED  and preset_x
eq 1 and (in09 fails or in09 eq 0) and dtyr ge .modelyr
      set var modelyr to (.modelyr-1)

  endwhile

else

  sho var notrees

endif

set var title to Juniper calculations
sho var title

set var title to Junipers: presettlement with increment
sho var title

*(for presettlement junipers w/ increment, calculate dshib_pr and dbh_pr)
update over set dshib_pr = ((.95*dsh_x)-(2*in09)) where species eq JUOS and preset_x eq 1 and in09 exists and in09
gt 0
update over set dbh_pr = (((dshib_pr/.95)*.953)-.713) where species eq JUOS and preset_x eq 1 and in09 exists and
in09 gt 0

set var title to Utah and other junipers: presettlement without increment
sho var title

*(for presettlement Utah + other junipers w/o increment, calculate dbh_pr iteratively using ECOSIM eqn.)
set var tstcnt integer
compute tstcnt as count tree# from over where species eq JUOS and preset_x eq 1 and (in09 fails or in09 eq 0)
*(set var tstcnt to 0)

if tstcnt gt 0 then

 set var modelyr integer
 set var modelyr to .iny
 set var title to Juniper model year:
 update over set dbh_pr = dbh_x where species eq JUOS and preset_x eq 1 and (in09 fails or in09 eq 0)
   while modelyr gt .exy then

      sho var title
      sho var modelyr
      update over set dbh_pr = (dbh_pr-((.0557989-(.000647*(dbh_pr/2.54)))*2.54)) where species eq JUOS and
preset_x eq 1 and (in09 fails or in09 eq 0) and dtyr ge .modelyr
      set var modelyr to (.modelyr-1)

   endwhile

 else

   sho var notrees
```

```
endif

set var title to Correct for negative presettlement dbh
sho var title
set var title to All species:
sho var title
update over set dbh_pr = 0 where species eq PIPO and dbh_pr lt 0
update over set dbh_pr = 0 where species eq PSME and dbh_pr lt 0
update over set dbh_pr = 0 where species eq ABCO and dbh_pr lt 0
update over set dbh_pr = 0 where species eq PIED and dbh_pr lt 0
update over set dbh_pr = 0 where species eq QUGA and dbh_pr lt 0
update over set dbh_pr = 0 where species eq POTR and dbh_pr lt 0
update over set dbh_pr = 0 where species eq JUOS and dbh_pr lt 0
update over set dbh_pr = 0 where species eq PIEN and dbh_pr lt 0
update over set dbh_pr = 0 where preset_x eq 1 and (in09 fails or in09 eq 0) and cond gt 2 and dtyr < (exyr+0)

set var title to Program complete
sho var title
```

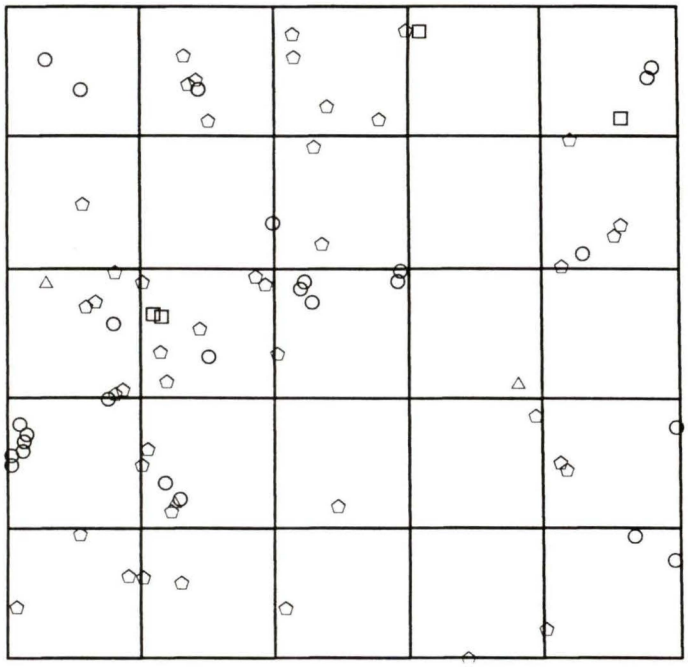
Appendix IV:

Maps of tree locations at plot establishment (1909 - 1913) and remeasurement (1997 - 1999) dates


1910
Live
N
1998
Dead and Down
Live
Snag
Stump


CIBS2A
1910
Live
N
1997
Dead and Down
Live
Snag
Stump

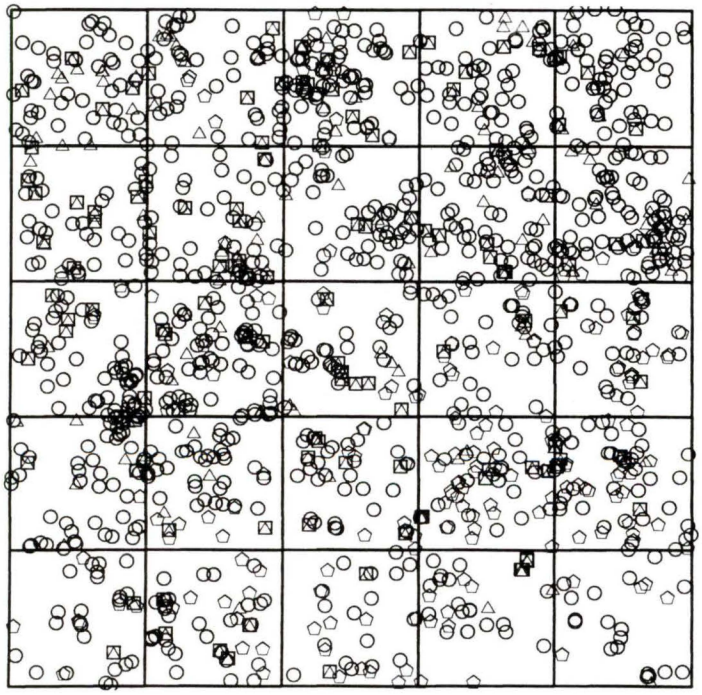
COCS1A



1909

- Dead and Down
- Live
- Snag
- Stump

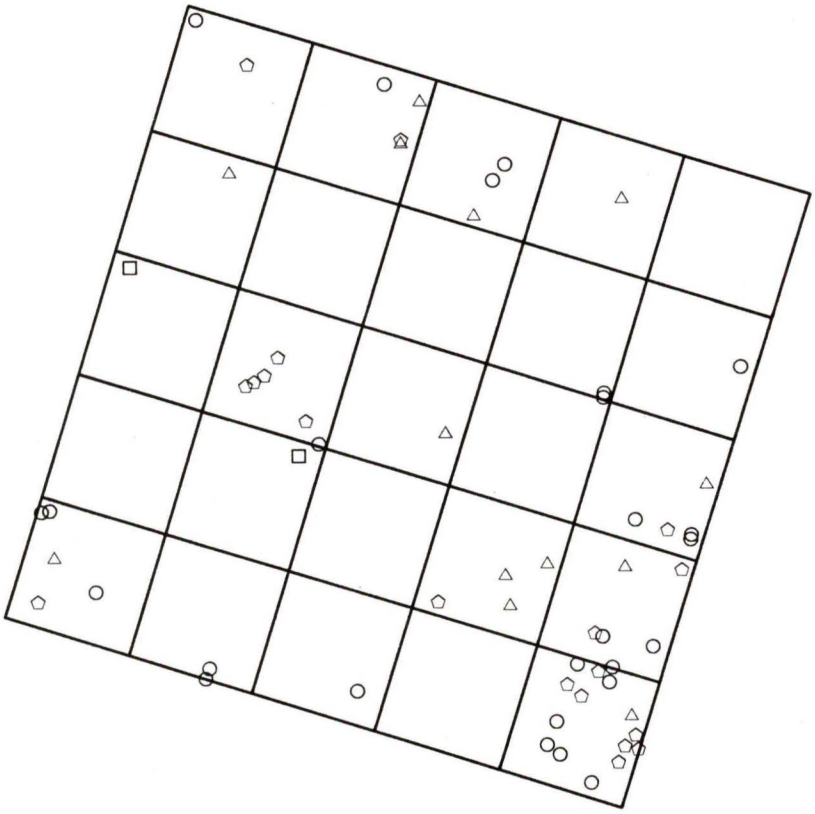
N



1997

- Dead and Down
- Live
- Snag
- Stump

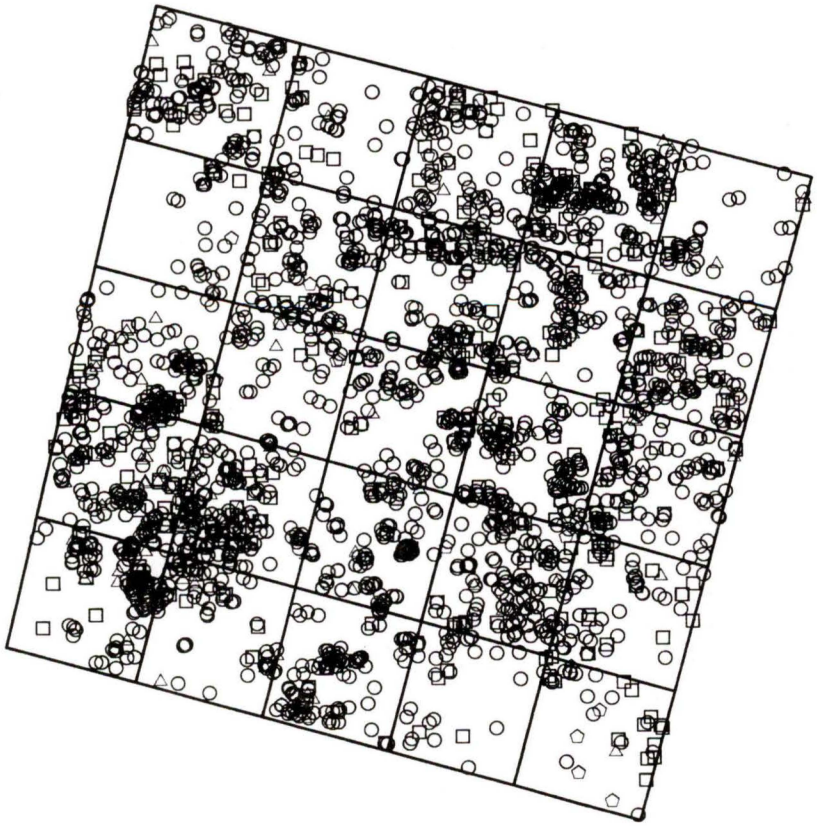
COCS1B



1901

- Dead and Down
- Live
- Snag
- Stump

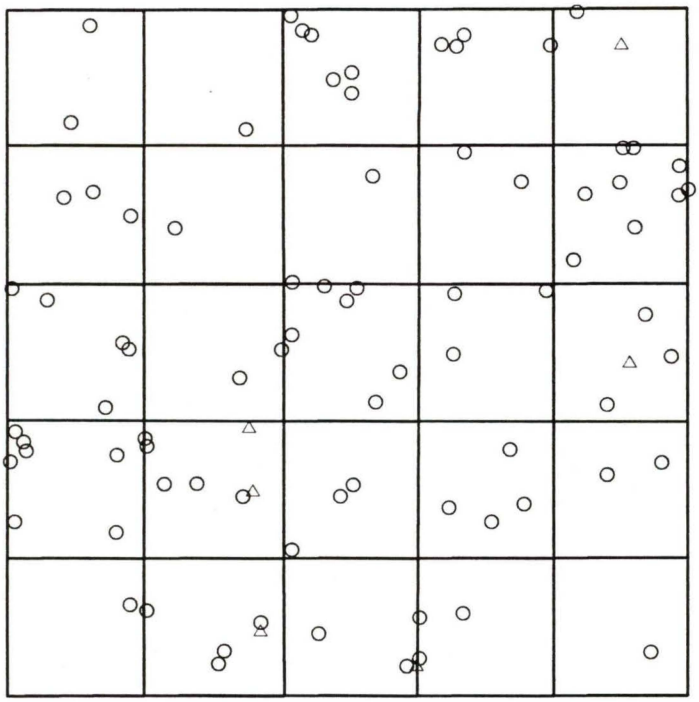
N



1997

- Dead and Down
- Live
- Snag
- Stump

COCS2A

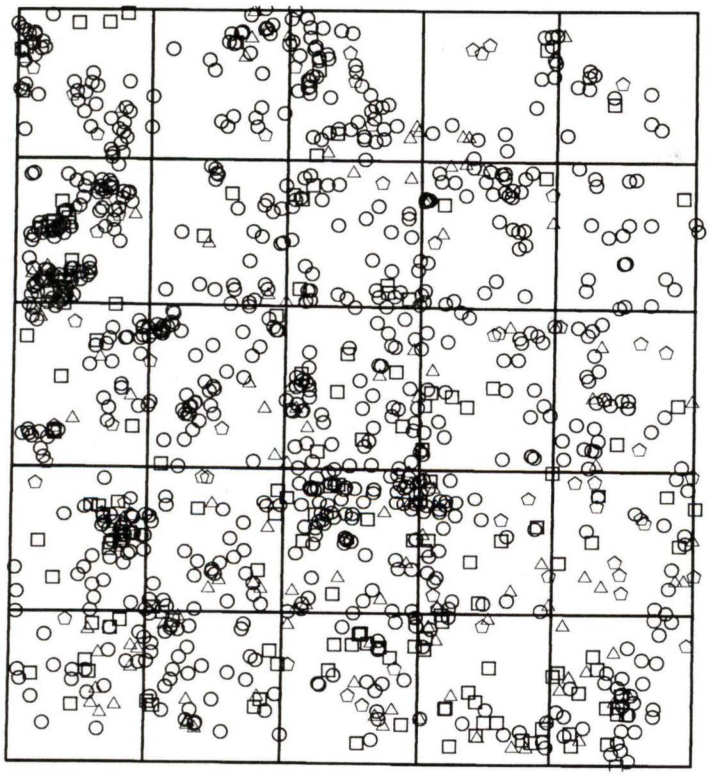


1909

Live

Snag

N



1998

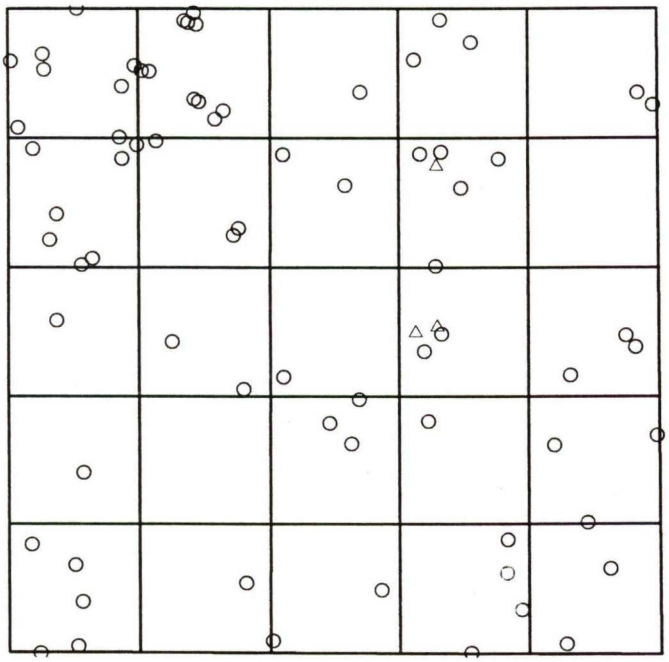
Dead and Down

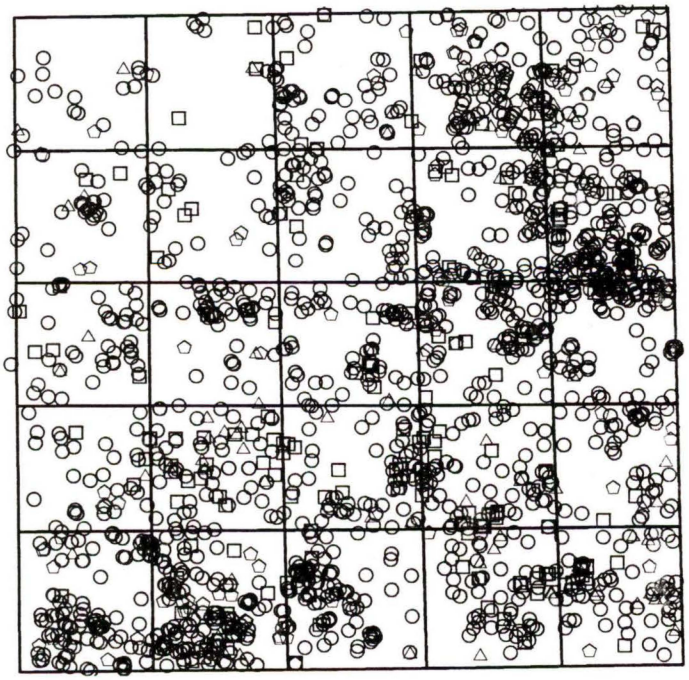
Live

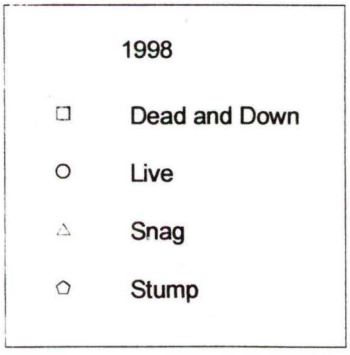
Snag

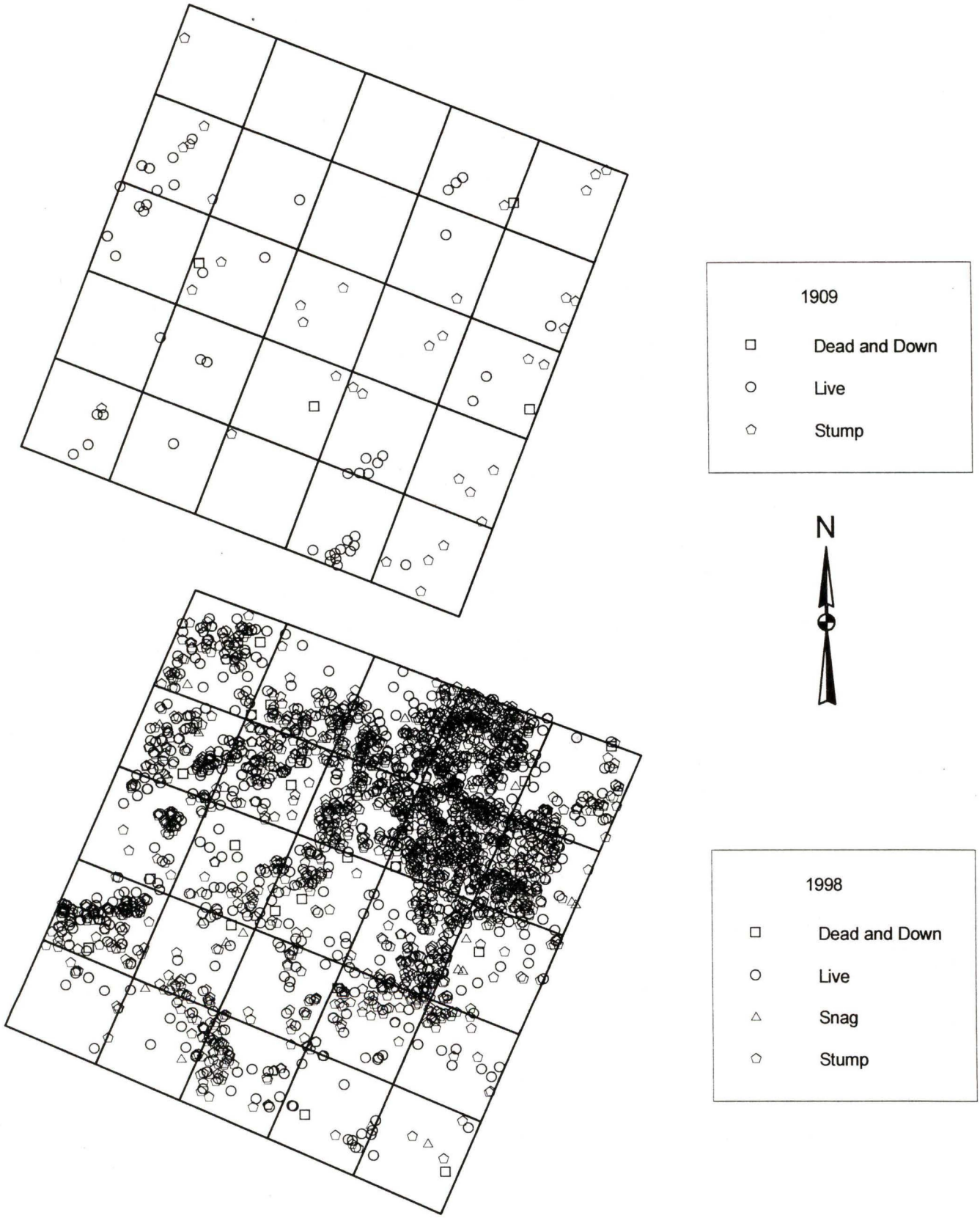
Stump

COCS2B

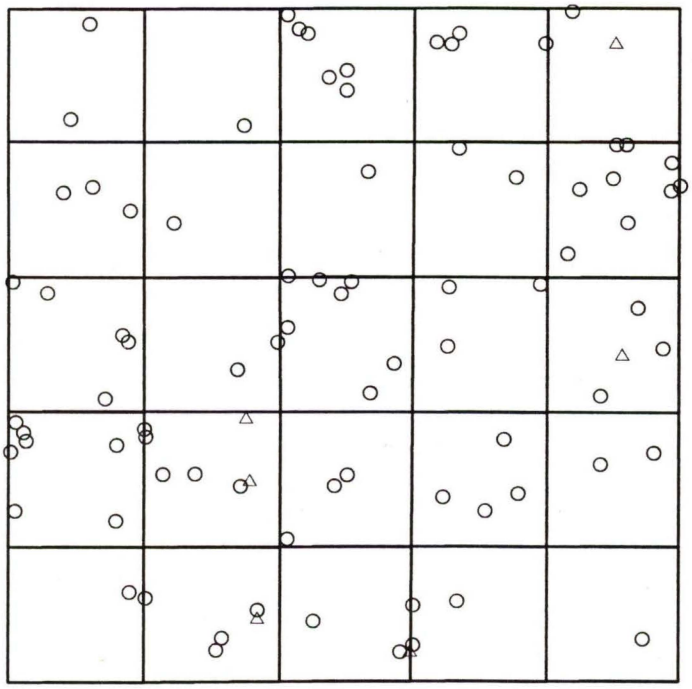


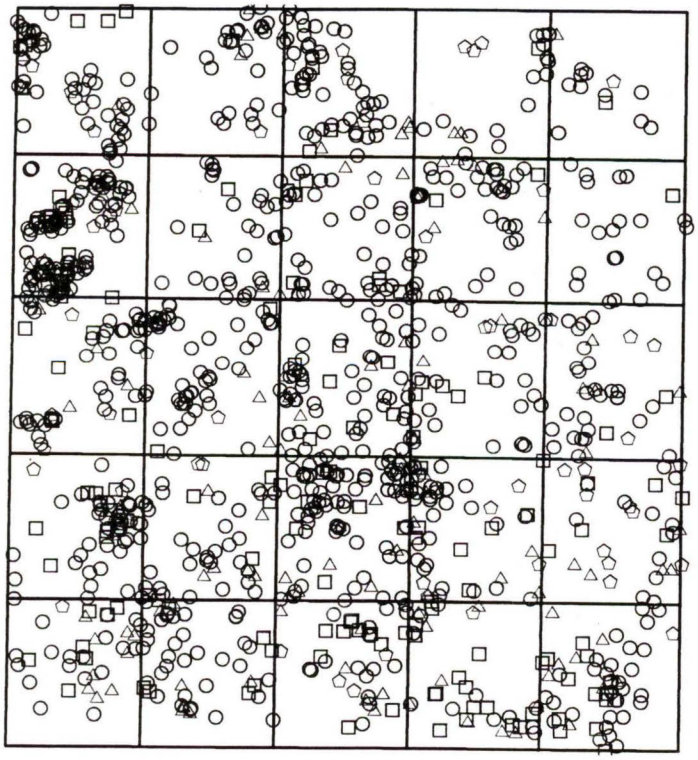





1909
Dead and Down
Live
Stump
N
1998
Dead and Down
Live
Snag
Stump

COCS3B





1909

Live

Snag

N

1998

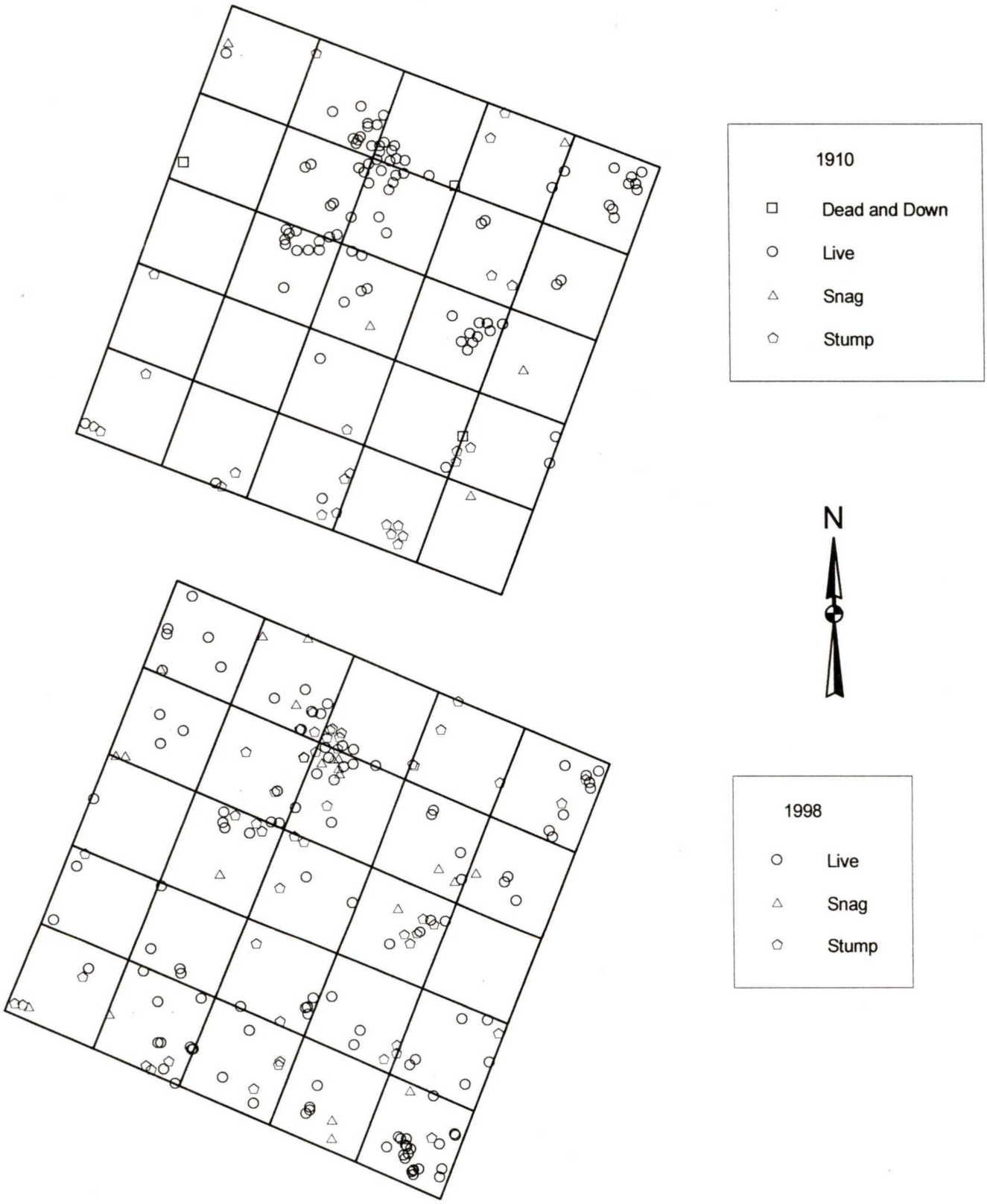
Dead and Down

Live

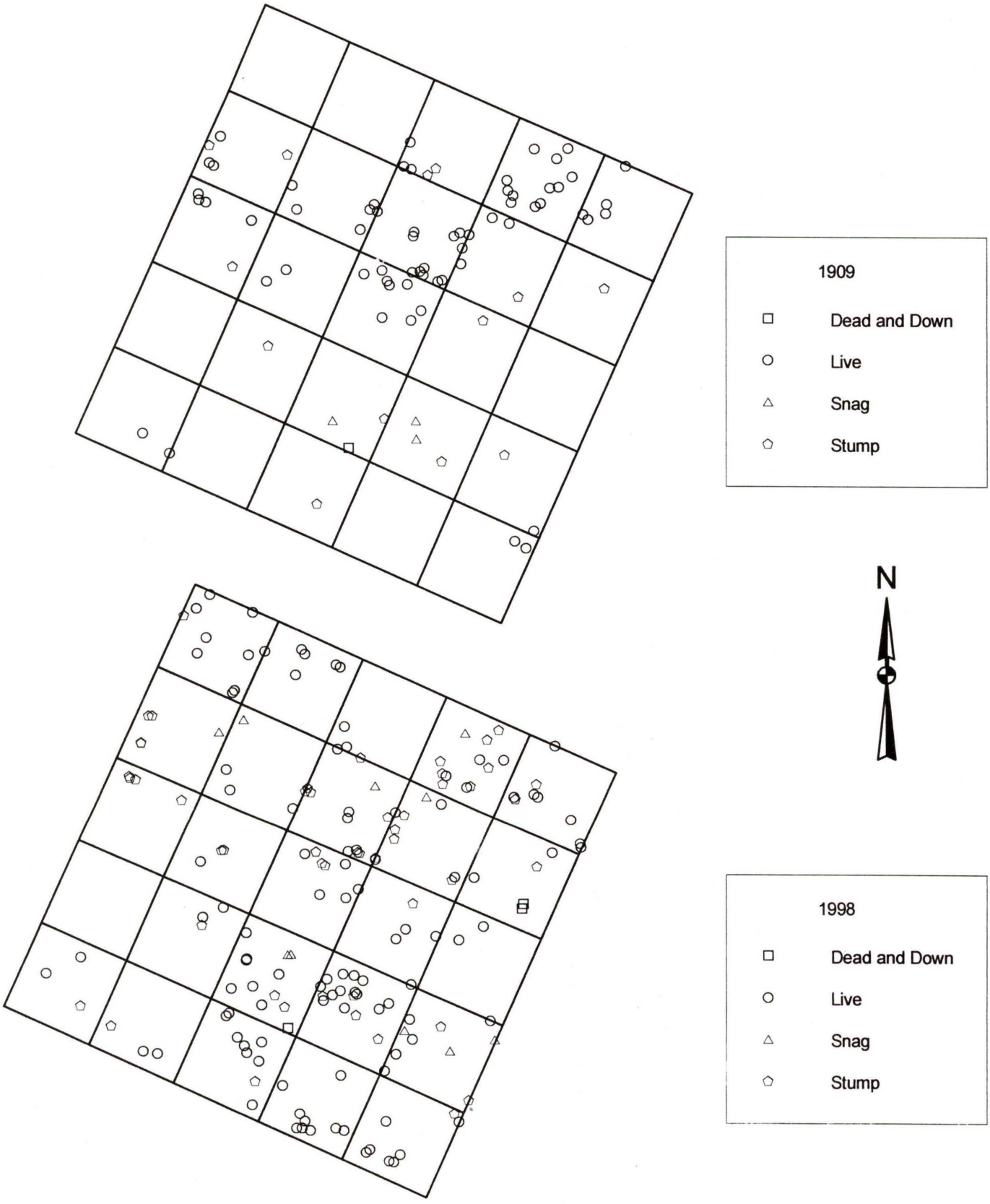
Snag

Stump

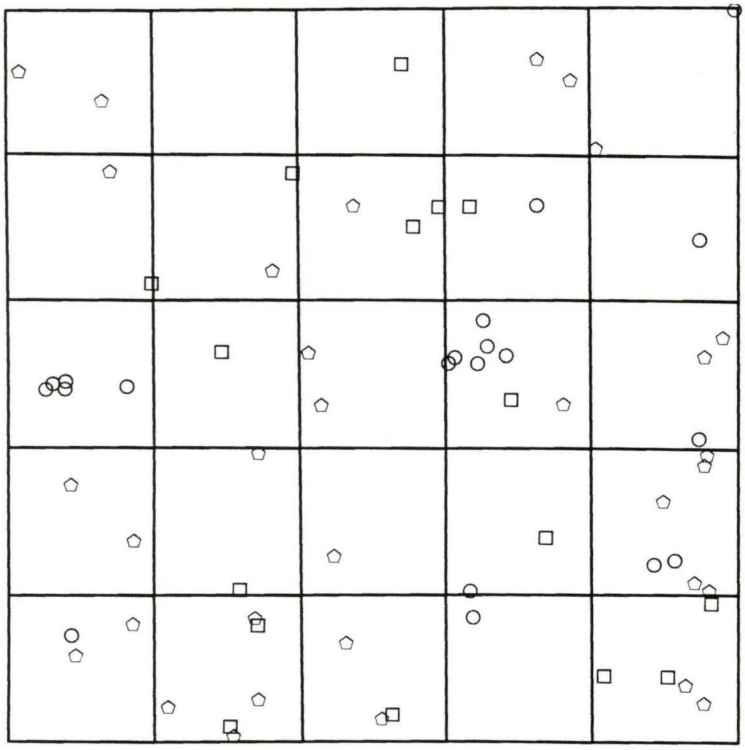
COCS4A



COCS4B


1909
Dead and Down
Live
Snag
Stump
N
1998
Dead and Down
Live
Snag
Stump

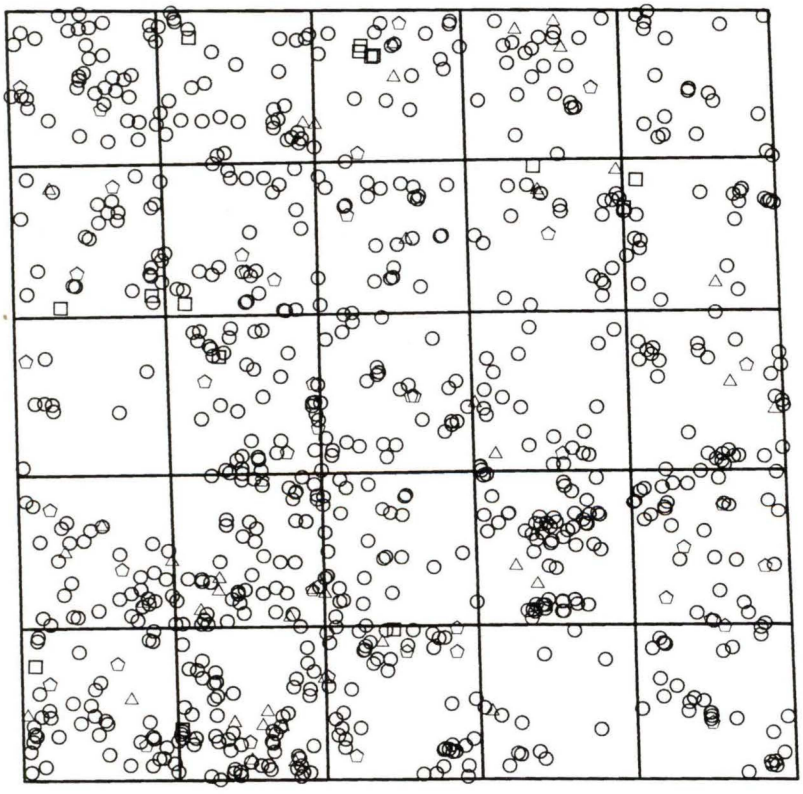
COCS5A2



1913

- Dead and Down
- Live
- Stump

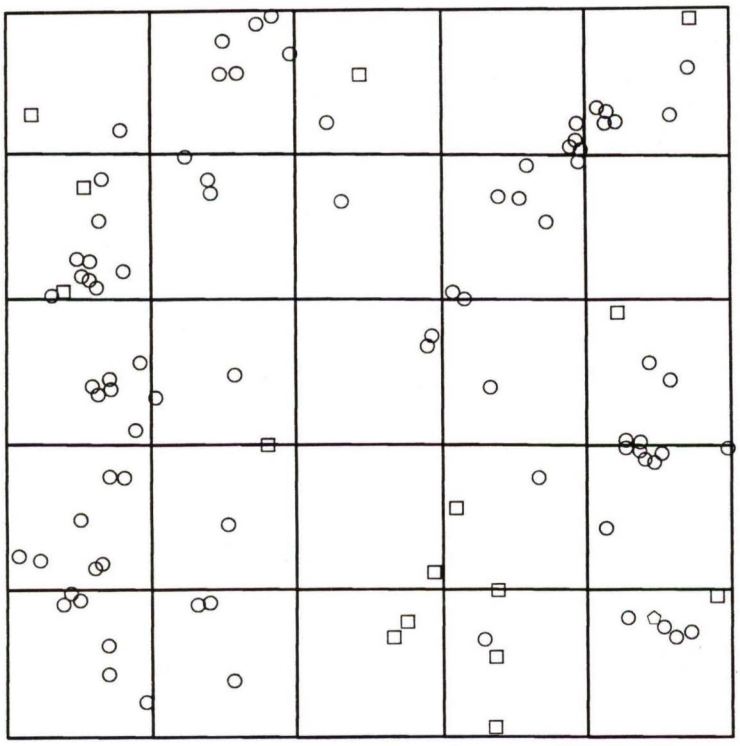
N



1998

- Dead and Down
- Live
- Snag
- Stump

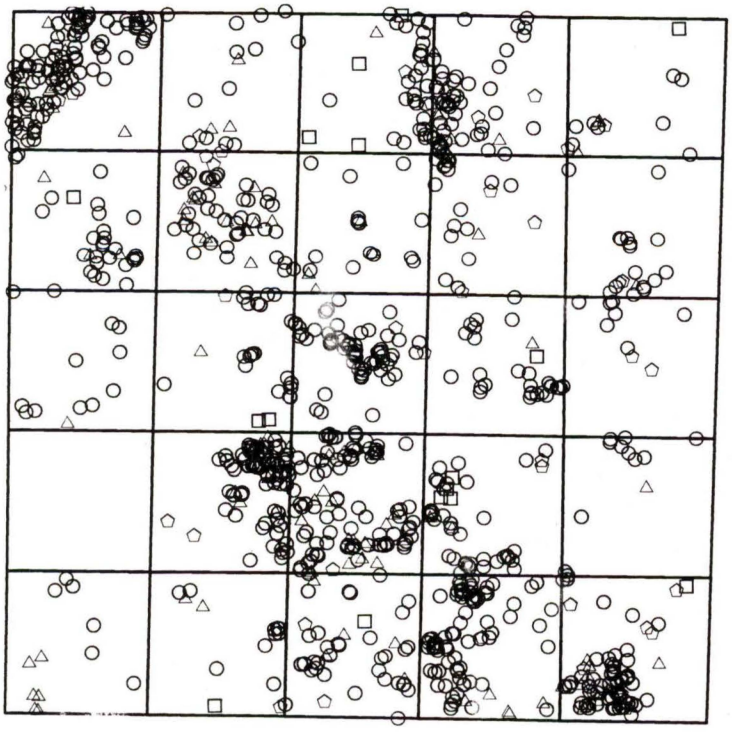
COCS5B3



1913

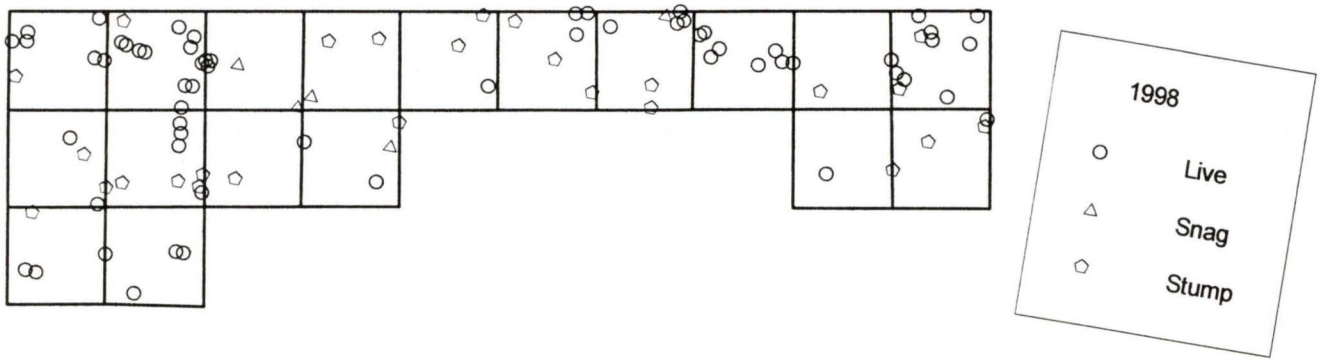
- Dead and Down
- Live
- Stump

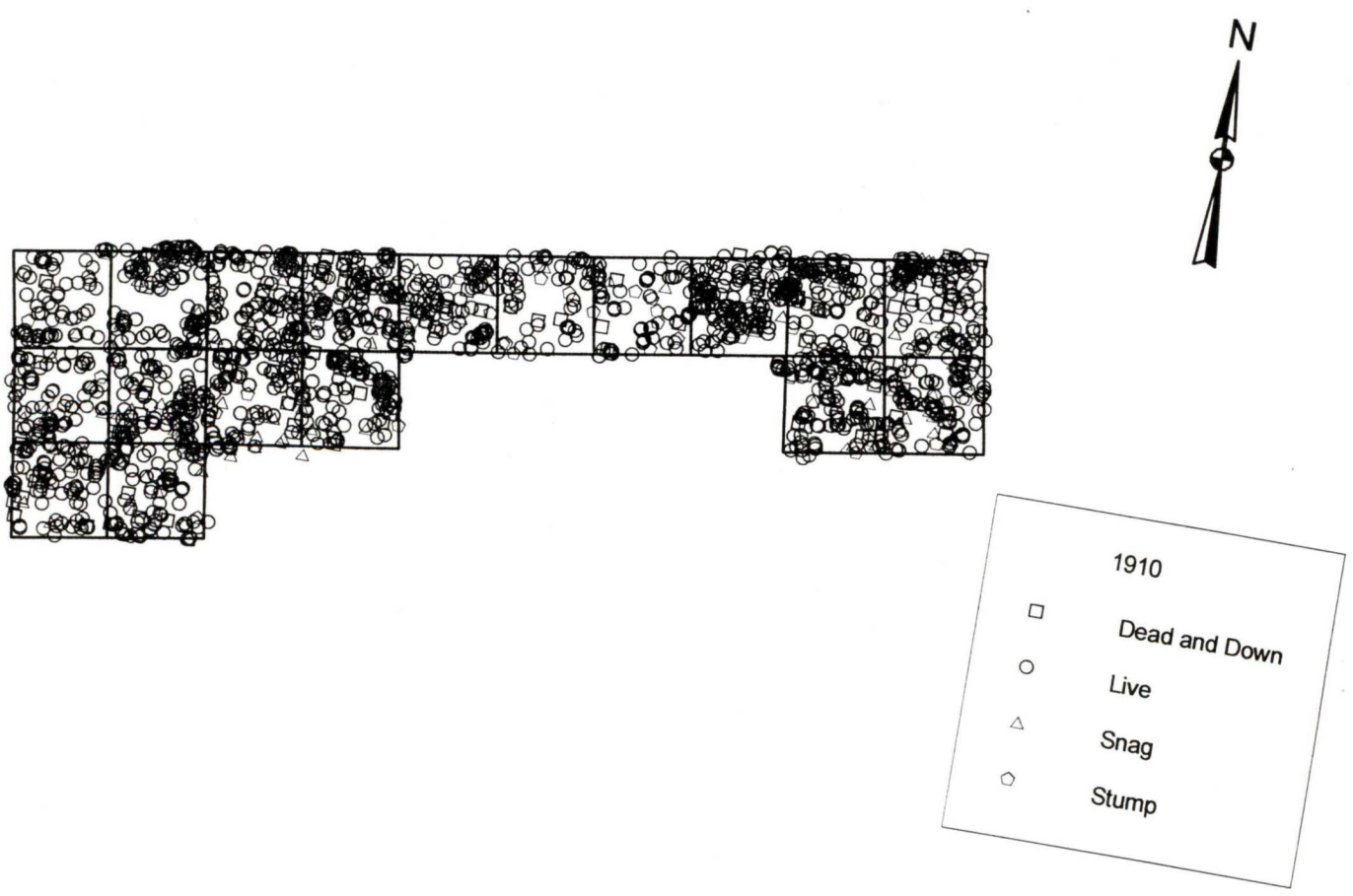
N

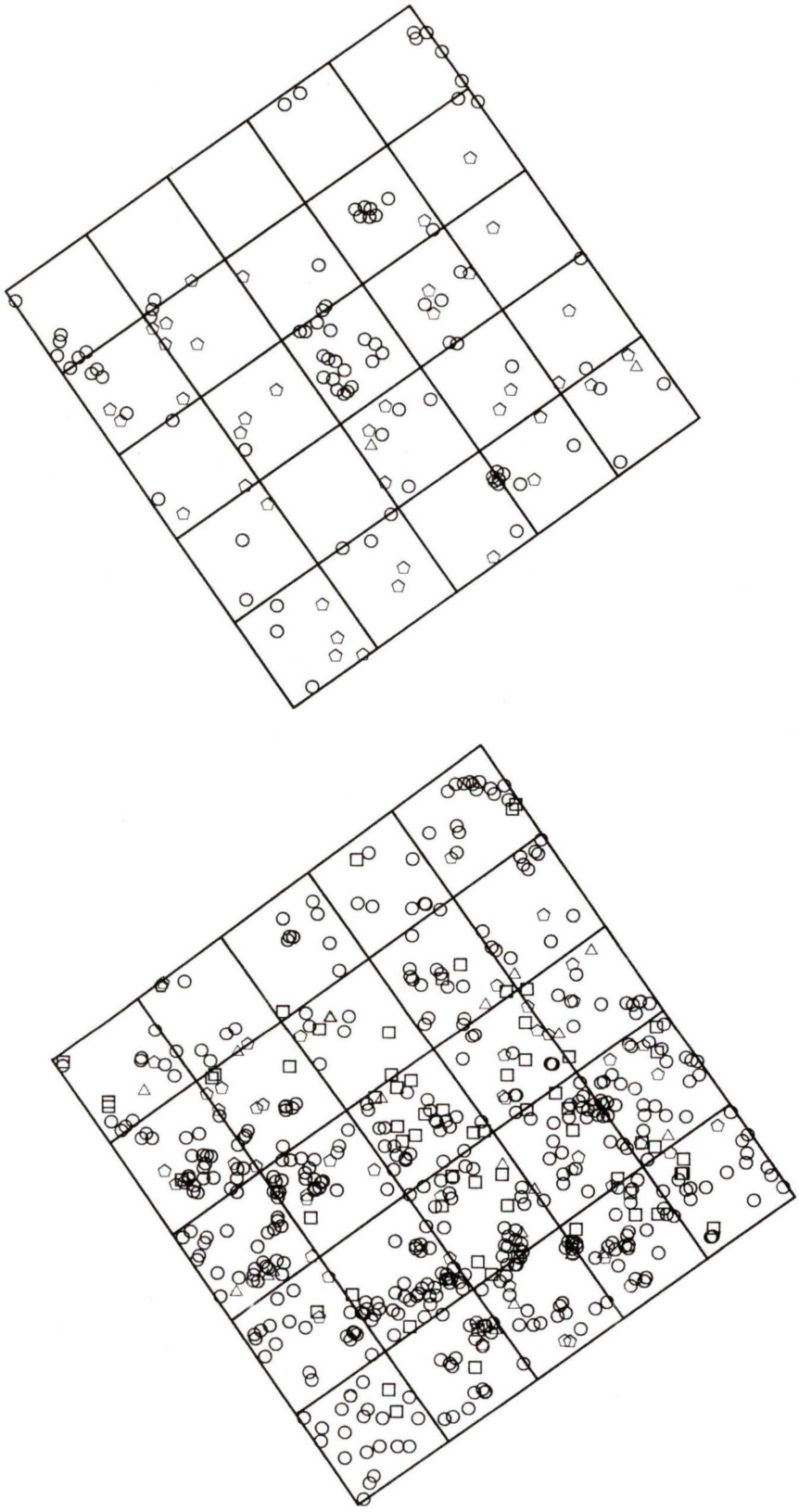


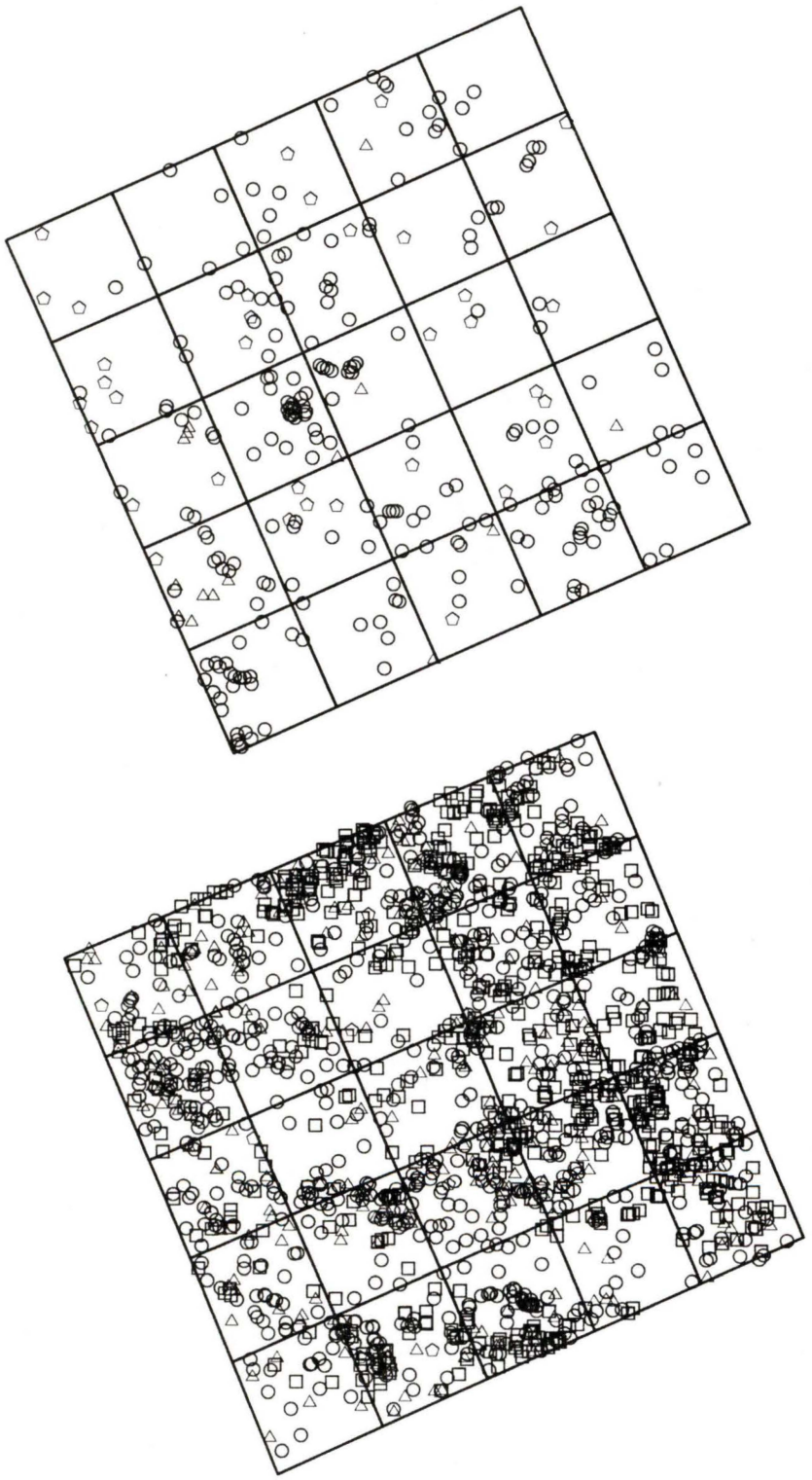
1998

- Dead and Down
- Live
- Snag
- Stump


1998
Live
Snag
Stump


N
1910
Dead and Down
Live
Snag
Stump

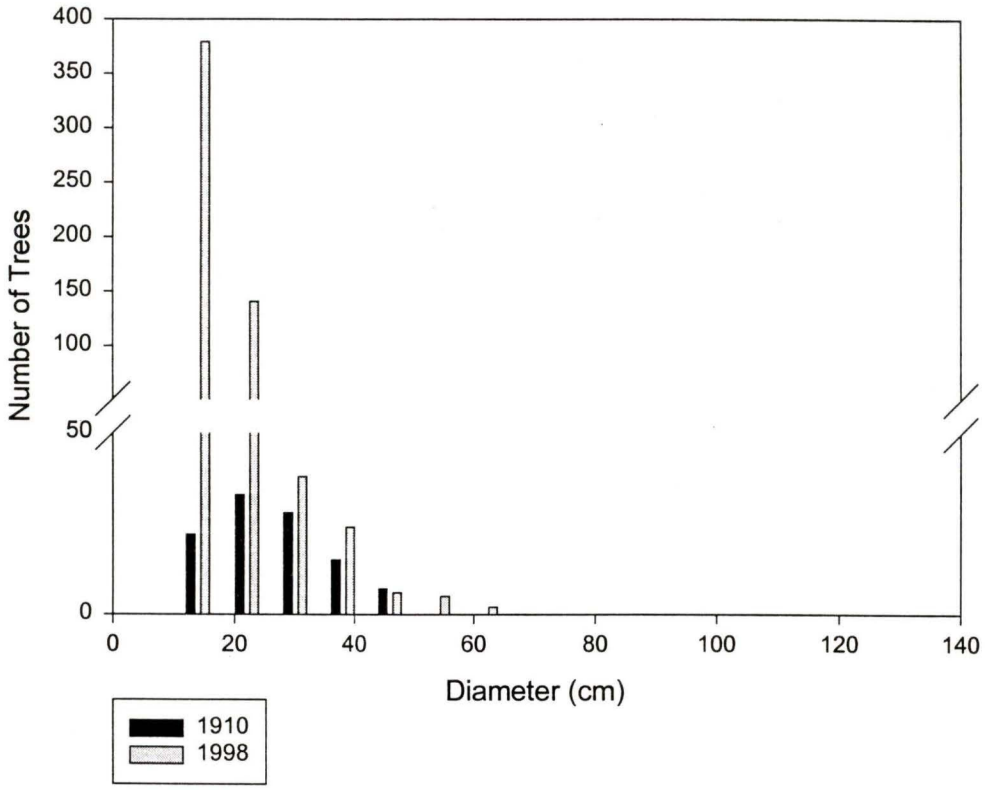

1911
Live
Snag
Stump
N
1998
Dead and Down
Live
Snag
Stump


1911
Live
Snag
Stump
N
1998
Dead and Down
Live
Snag
Stumps

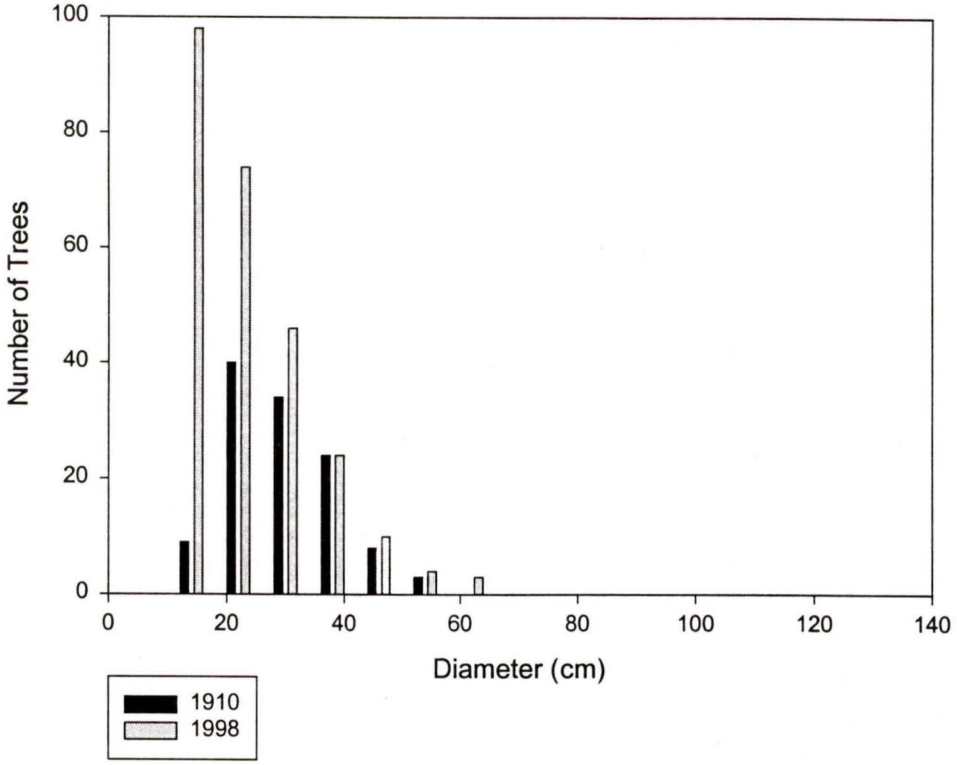
Appendix V:

Charts of historical (1909 - 1913) and remeasurement (1997 - 1999) diameter distributions

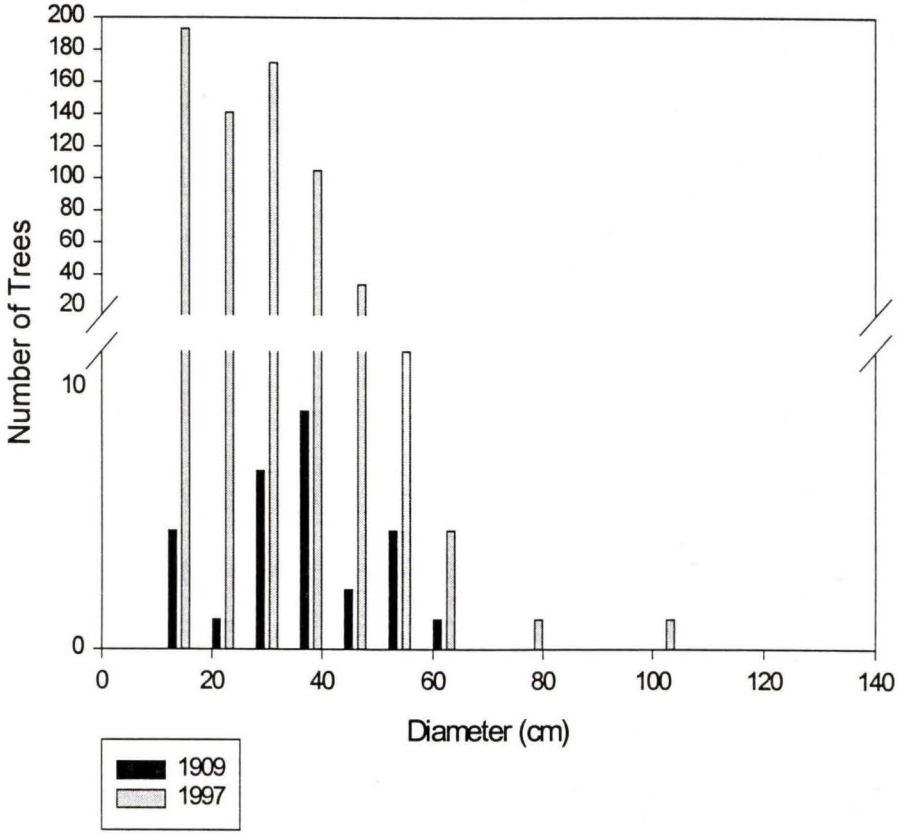
CIBS1A


400
350
300
250
200
150
100
50
0
Number of Trees
0
20
40
60
80
100
120
140
Diameter (cm)
1910
1998

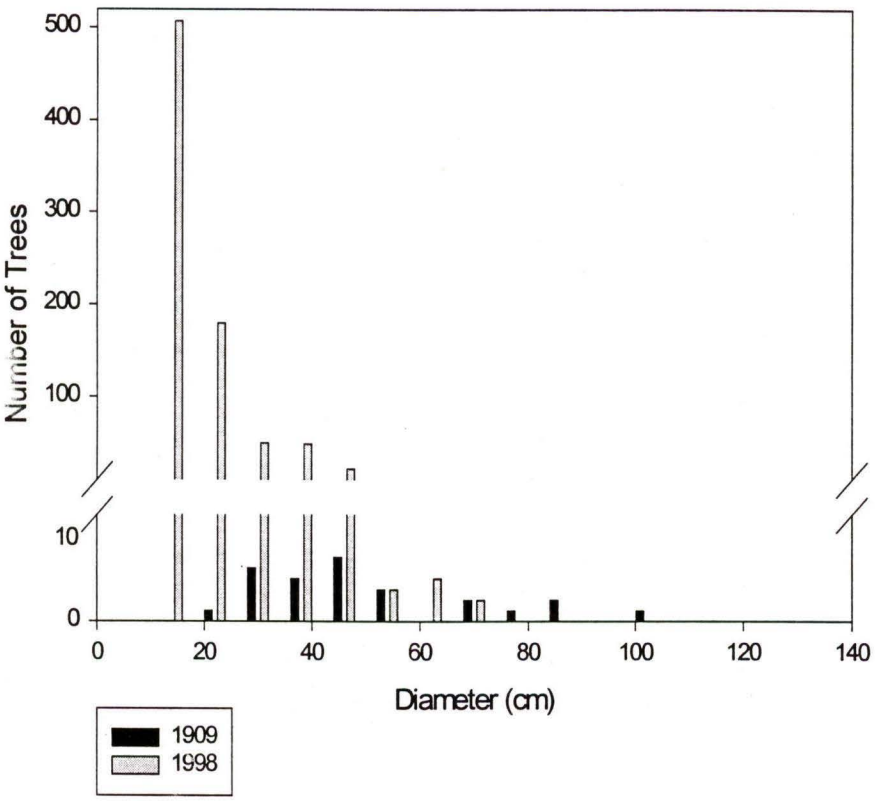
CIBS2A

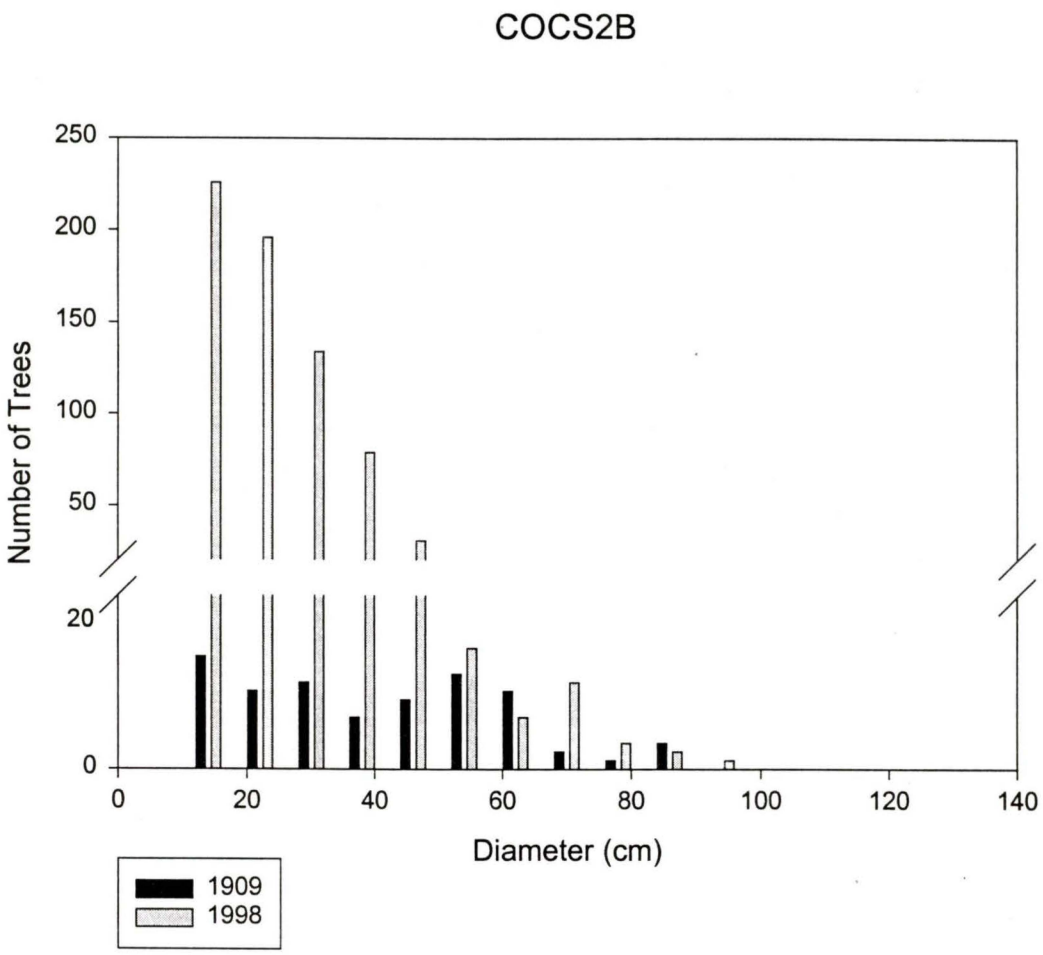

100
80
60
40
20
0
Number of Trees
0
20
40
60
80
100
120
140
Diameter (cm)
1910
1998

COCS1A

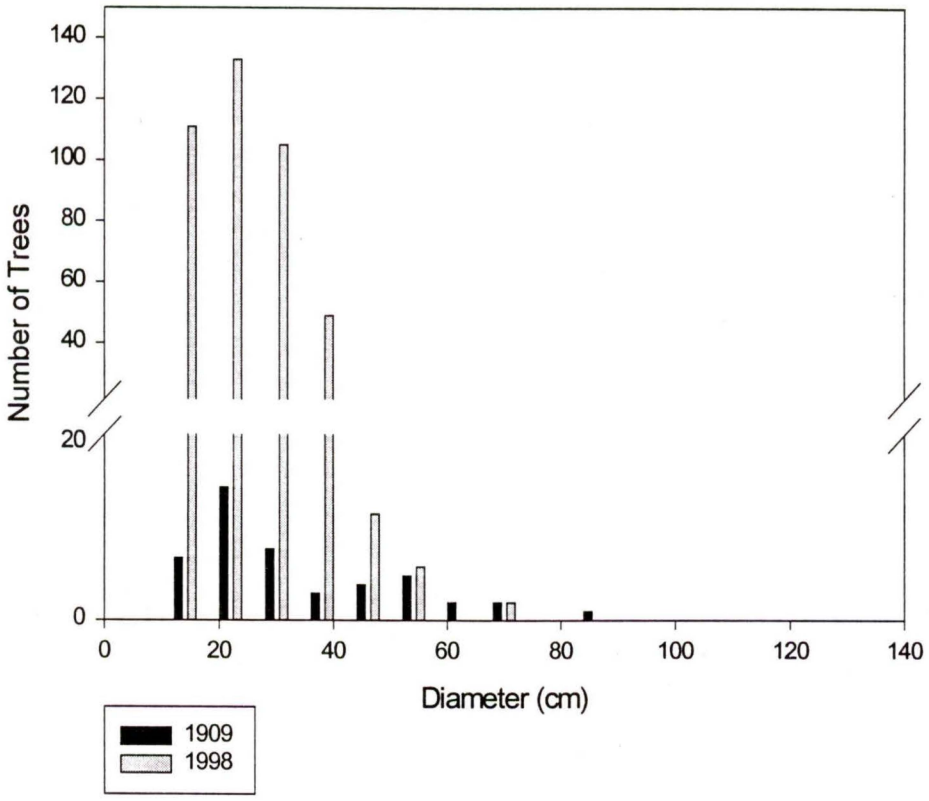

Number of Trees
200
180
160
140
120
100
80
60
40
20
10
0
0
20
40
60
80
100
120
140
Diameter (cm)
1909
1997

COCS1B

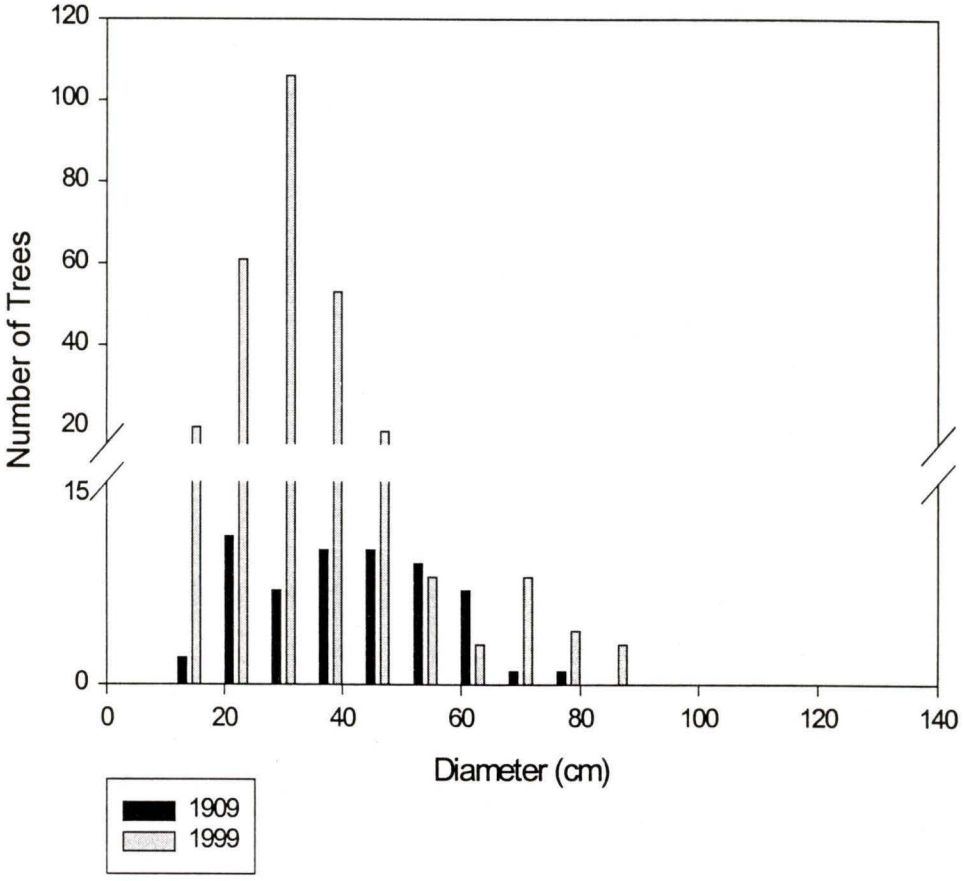

500
400
300
200
100
10
0
Number of Trees
0
20
40
60
80
100
120
140
Diameter (cm)
1909
1998


COCS2B
250
200
150
100
50
20
0
Number of Trees
0
20
40
60
80
100
120
140
Diameter (cm)
1909
1998

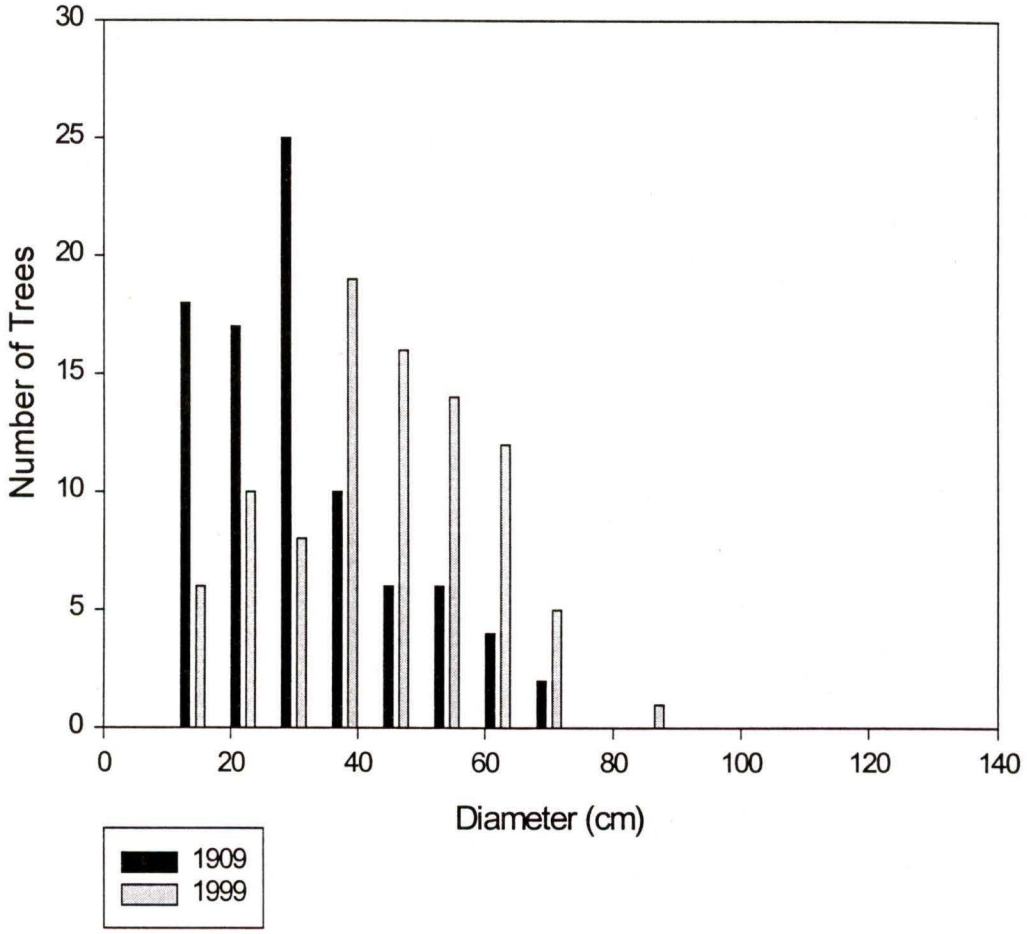
COCS3A


Number of Trees
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
Diameter (cm)
1909
1998

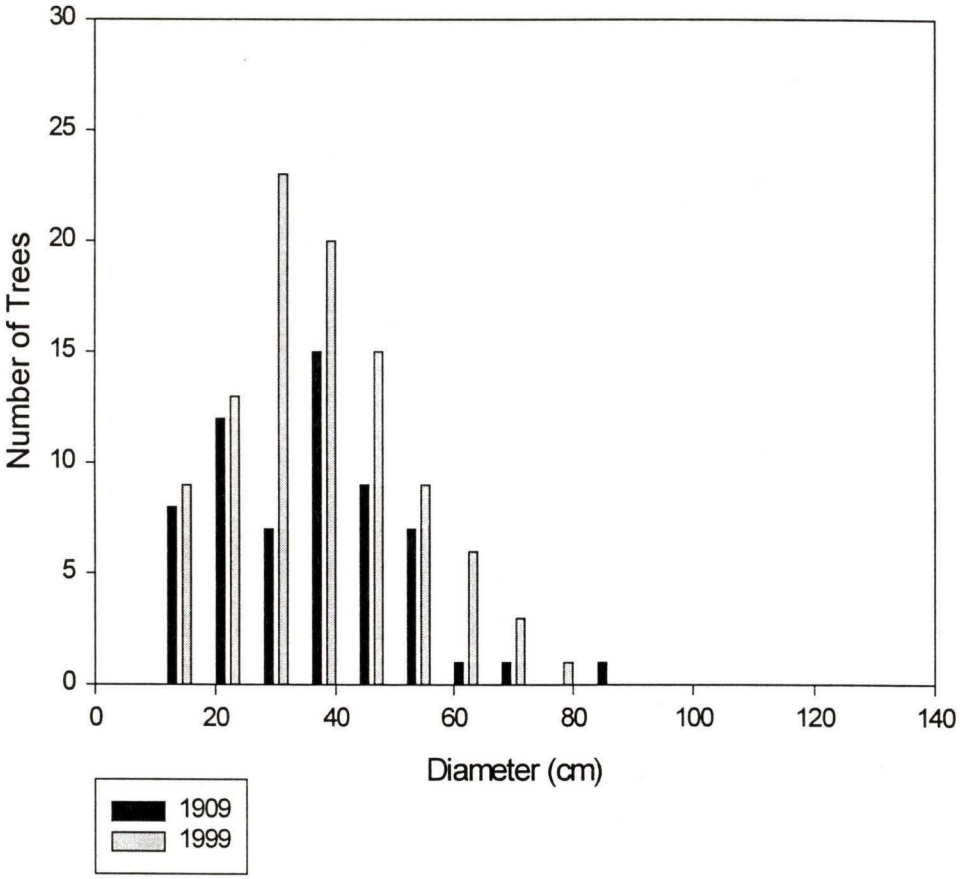
COCS3B


120
100
80
60
40
20
15
0
Number of Trees
0
20
40
60
80
100
120
140
Diameter (cm)
1909
1999

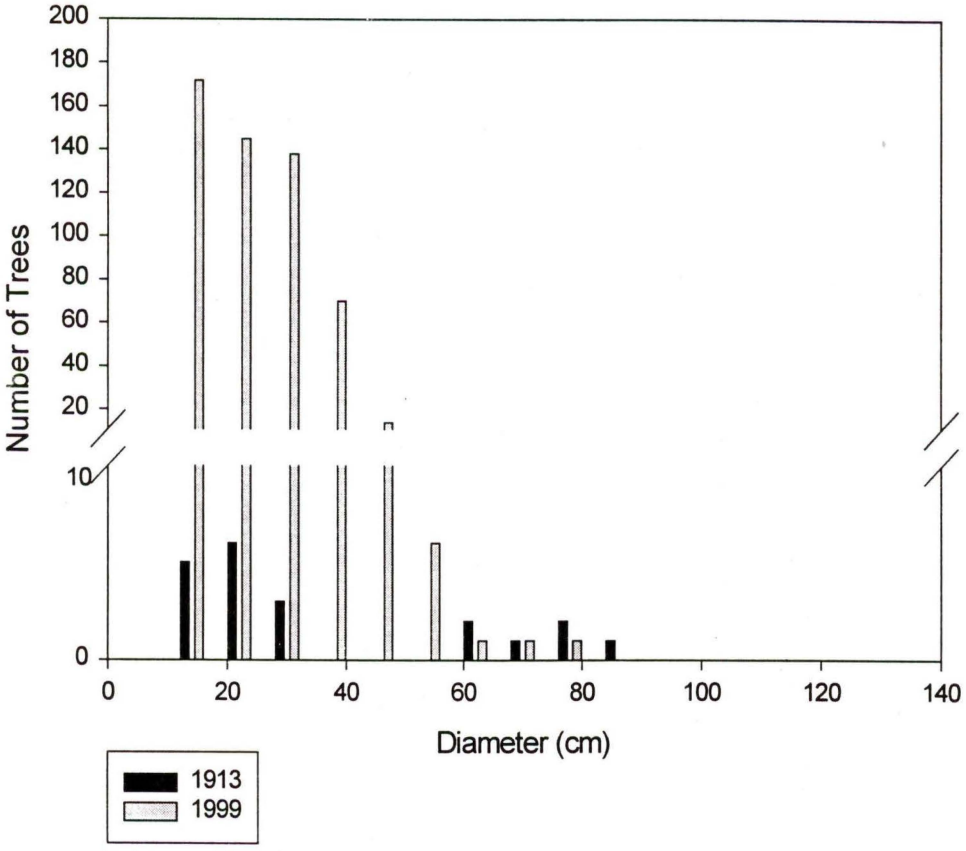
COCS4A

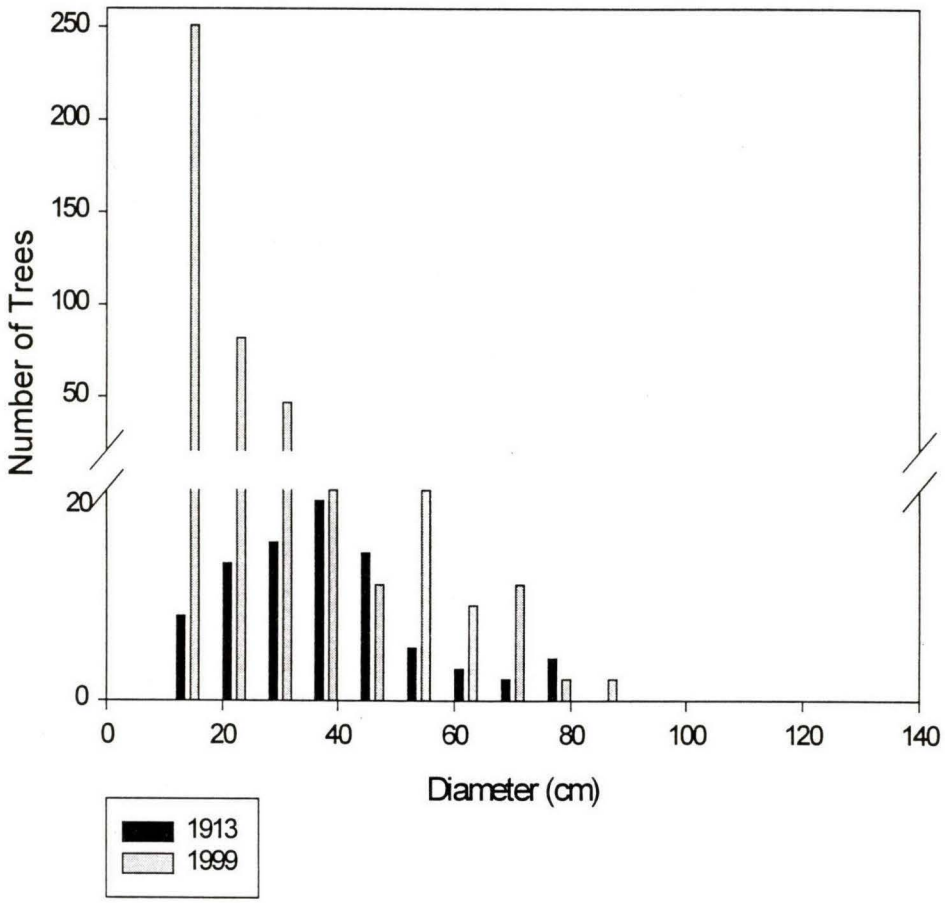

30
25
20
15
10
5
0
Number of Trees
0
20
40
60
80
100
120
140
Diameter (cm)
1909
1999

COCS4B

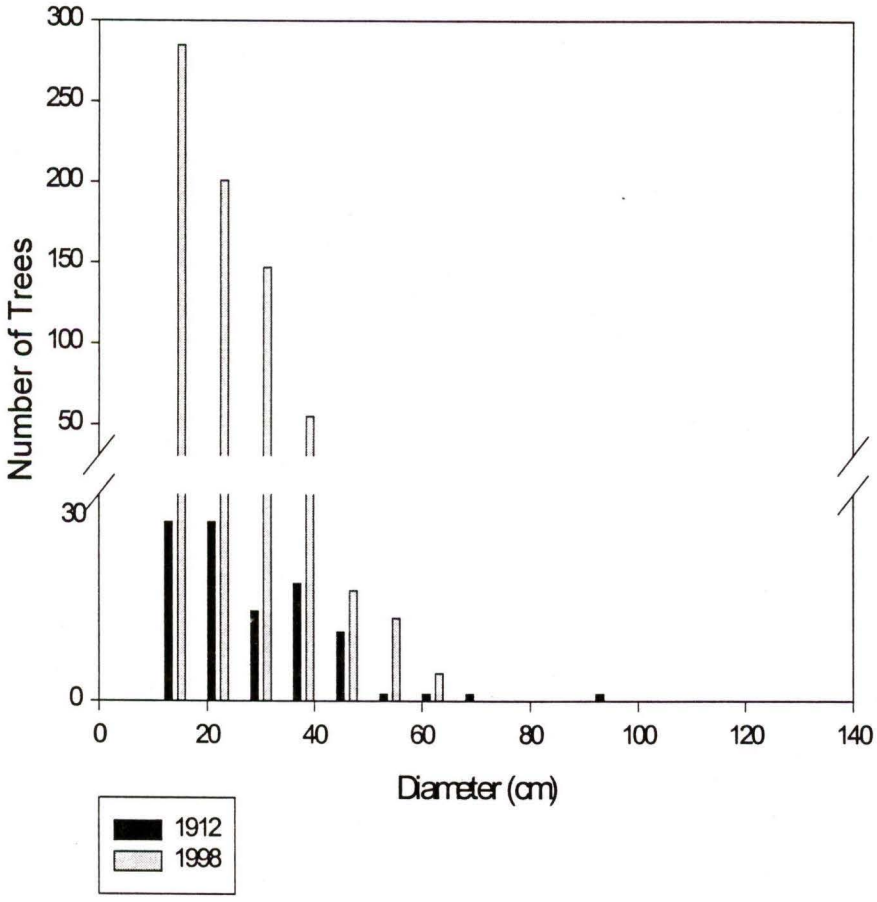

30
25
20
15
10
5
0
Number of Trees
0
20
40
60
80
100
120
140
Diameter (cm)
1909
1999

COCS5A2

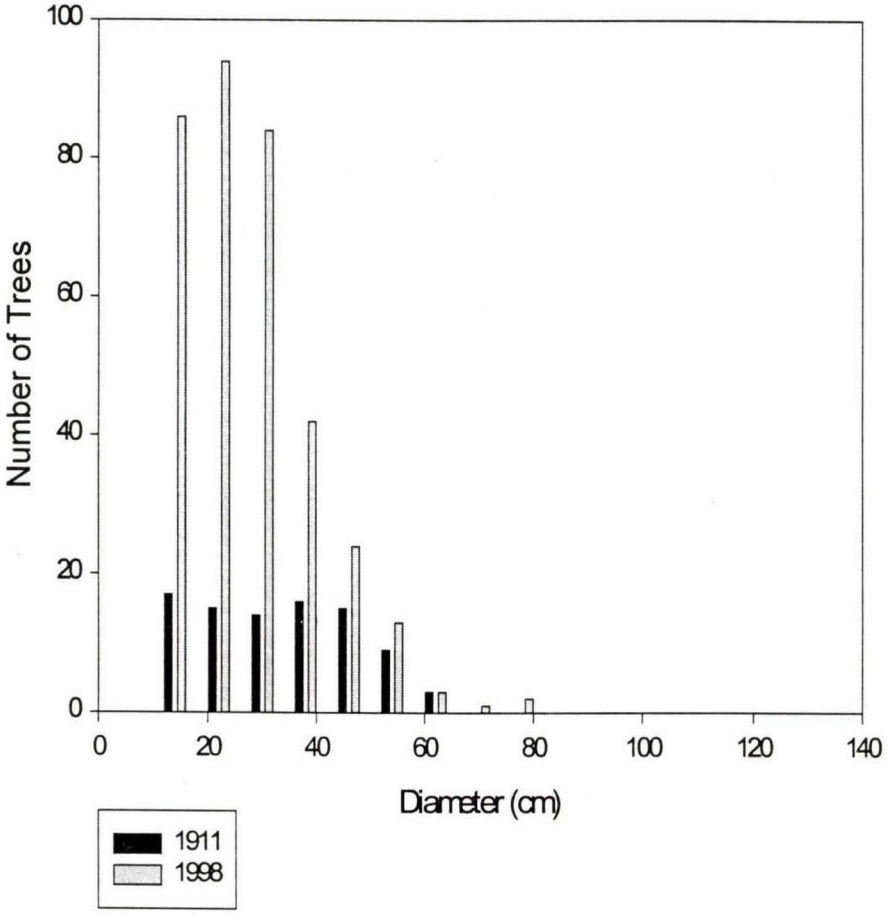

Number of Trees
200
180
160
140
120
100
80
60
40
20
10
0
0
20
40
60
80
100
120
140
Diameter (cm)
1913
1999


COCS5B3
Number of Trees
250
200
150
100
50
20
0
0
20
40
60
80
100
120
140
Diameter (cm)
1913
1999

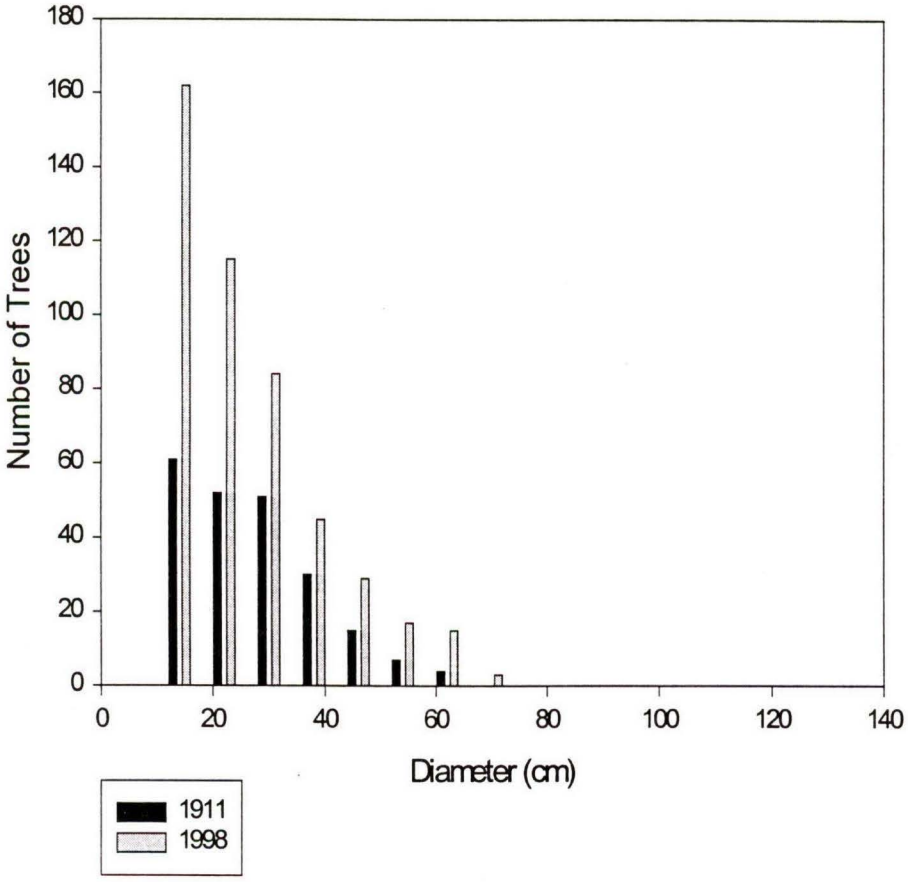
GILAS1A


300
250
200
150
100
50
30
0
Number of Trees
0
20
40
60
80
100
120
140
Diameter (cm)
1912
1998

JEMEZS2A

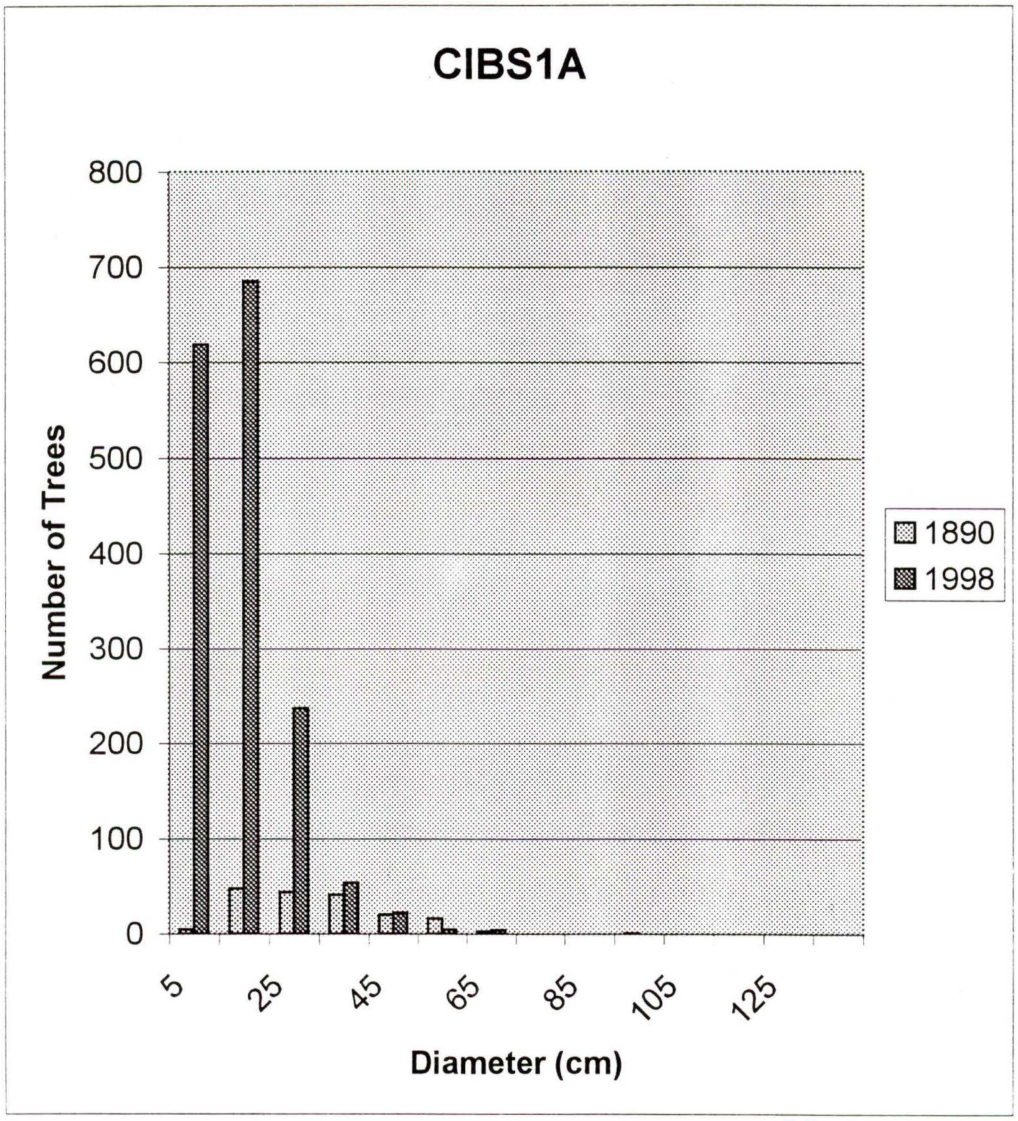

100
80
60
40
20
0
Number of Trees
0
20
40
60
80
100
120
140
Diameter (cm)
1911
1998

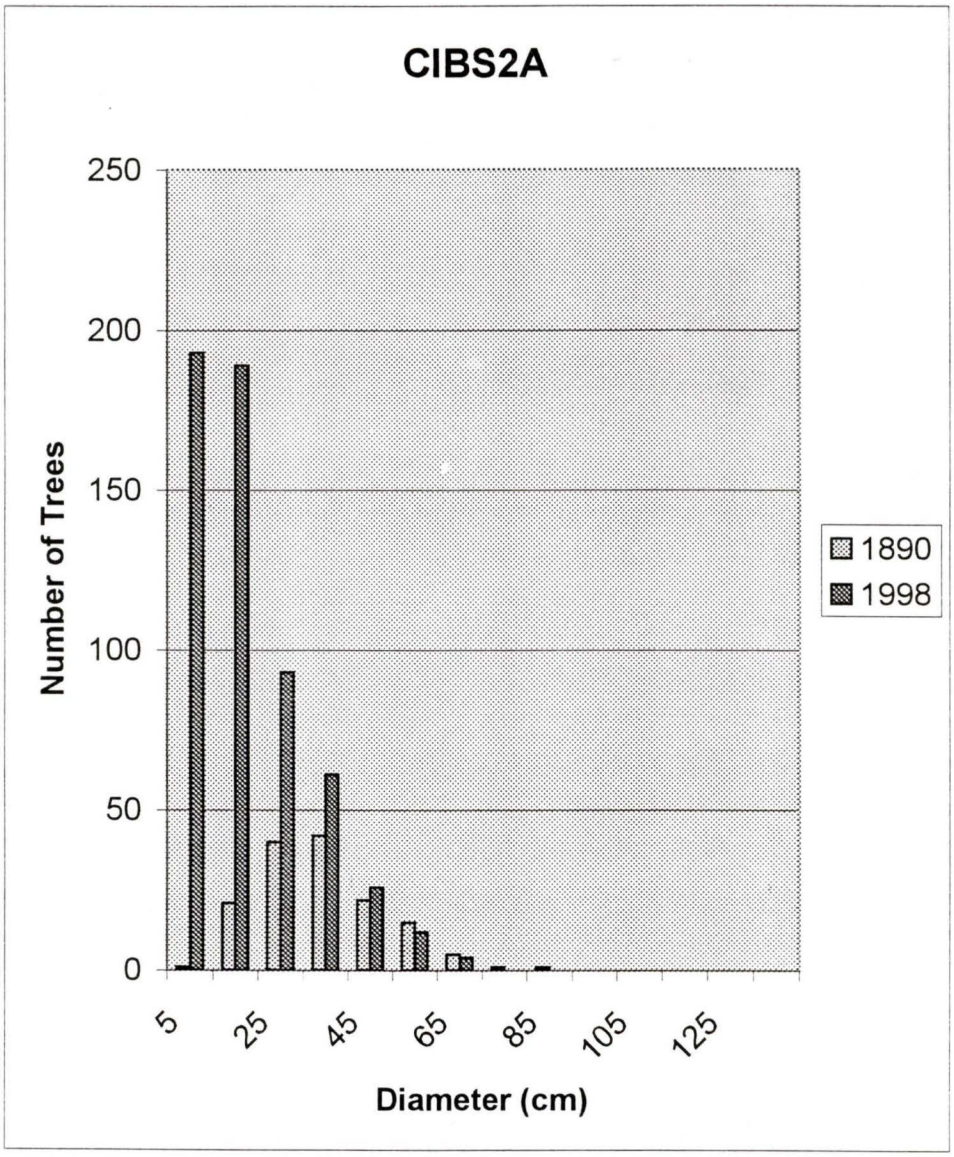
JEMEZS3A

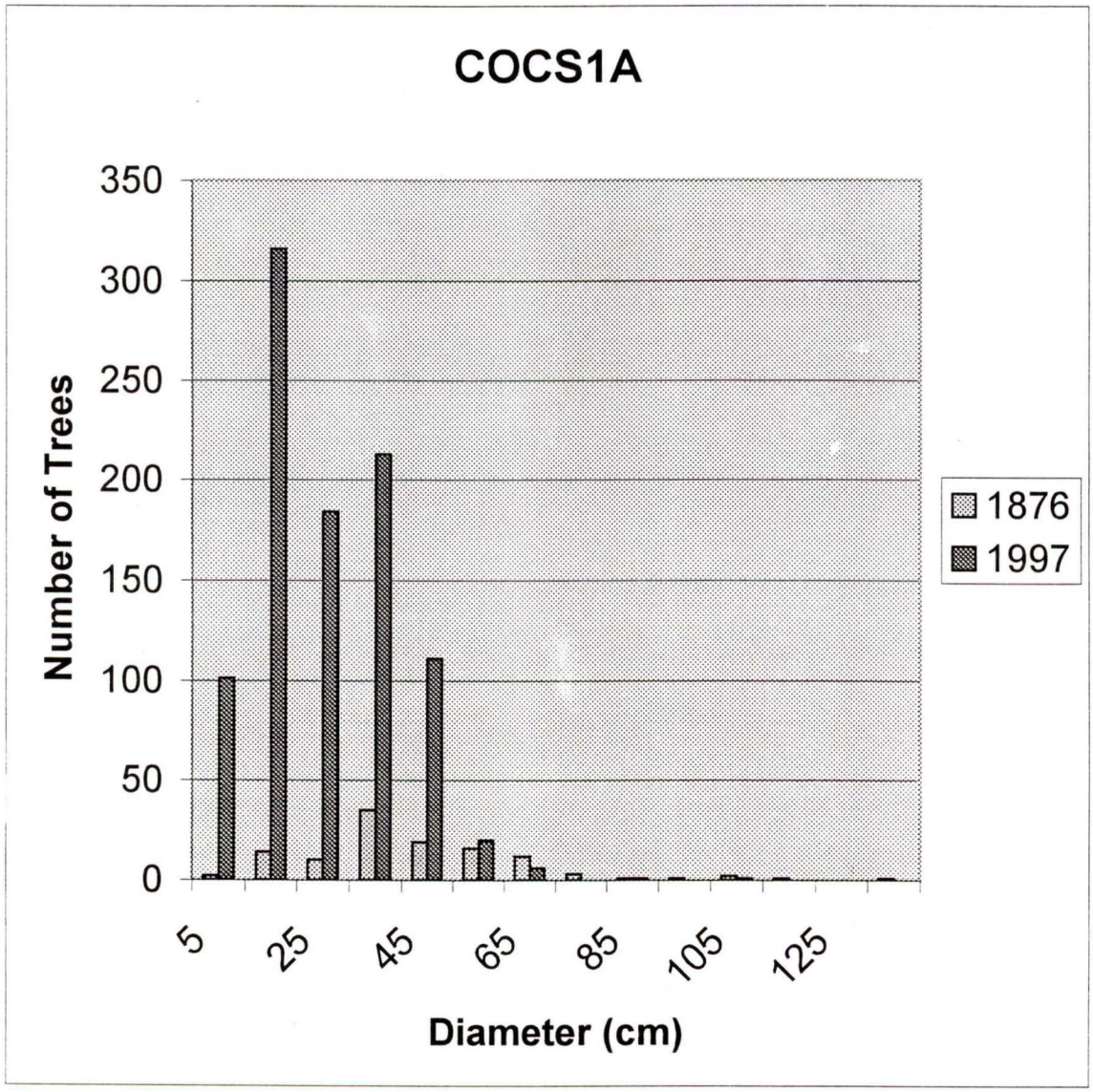

180
160
140
120
100
80
60
40
20
0
Number of Trees
0
20
40
60
80
100
120
140
Diameter (cm)
1911
1998

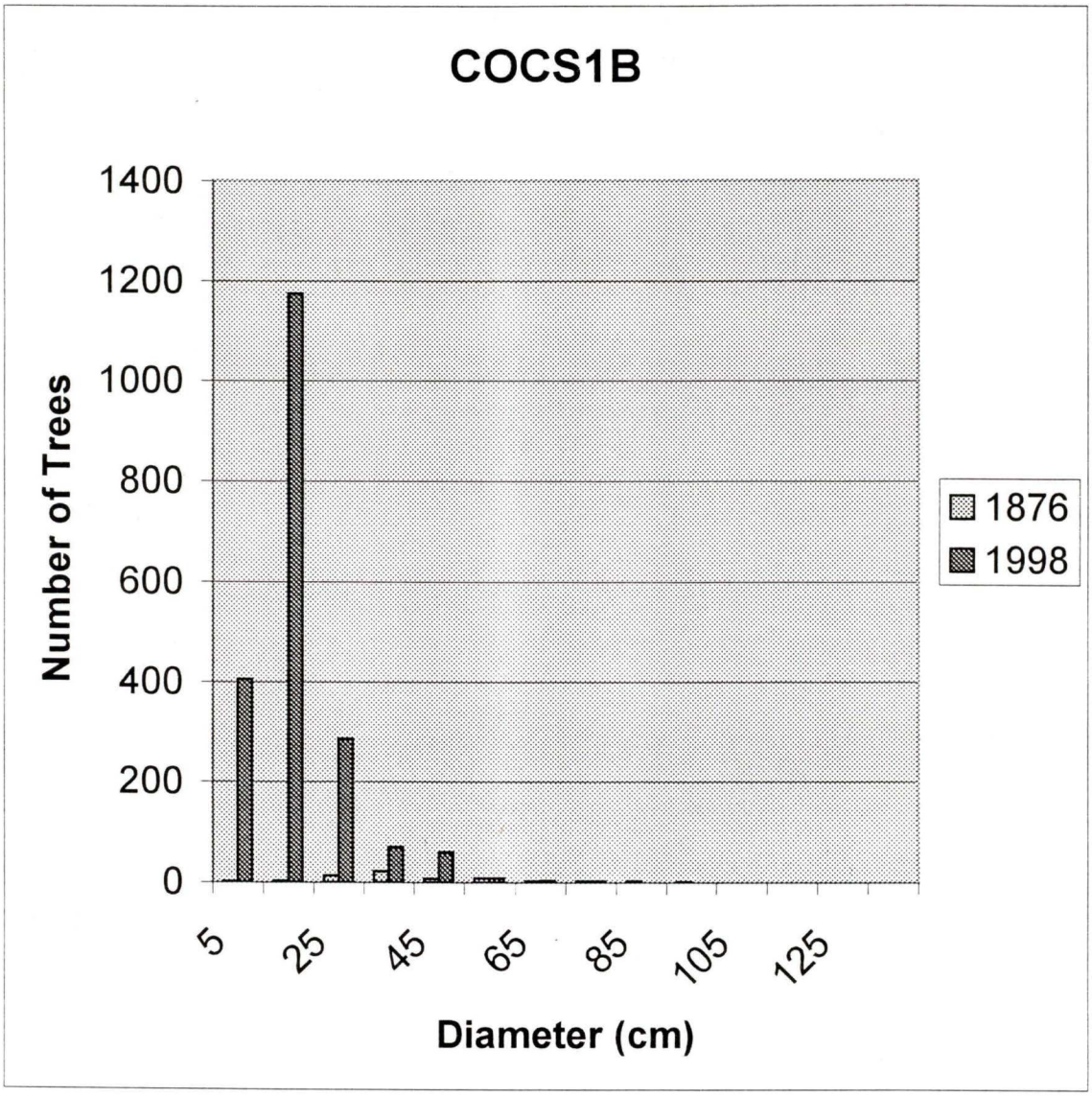
Appendix VI:

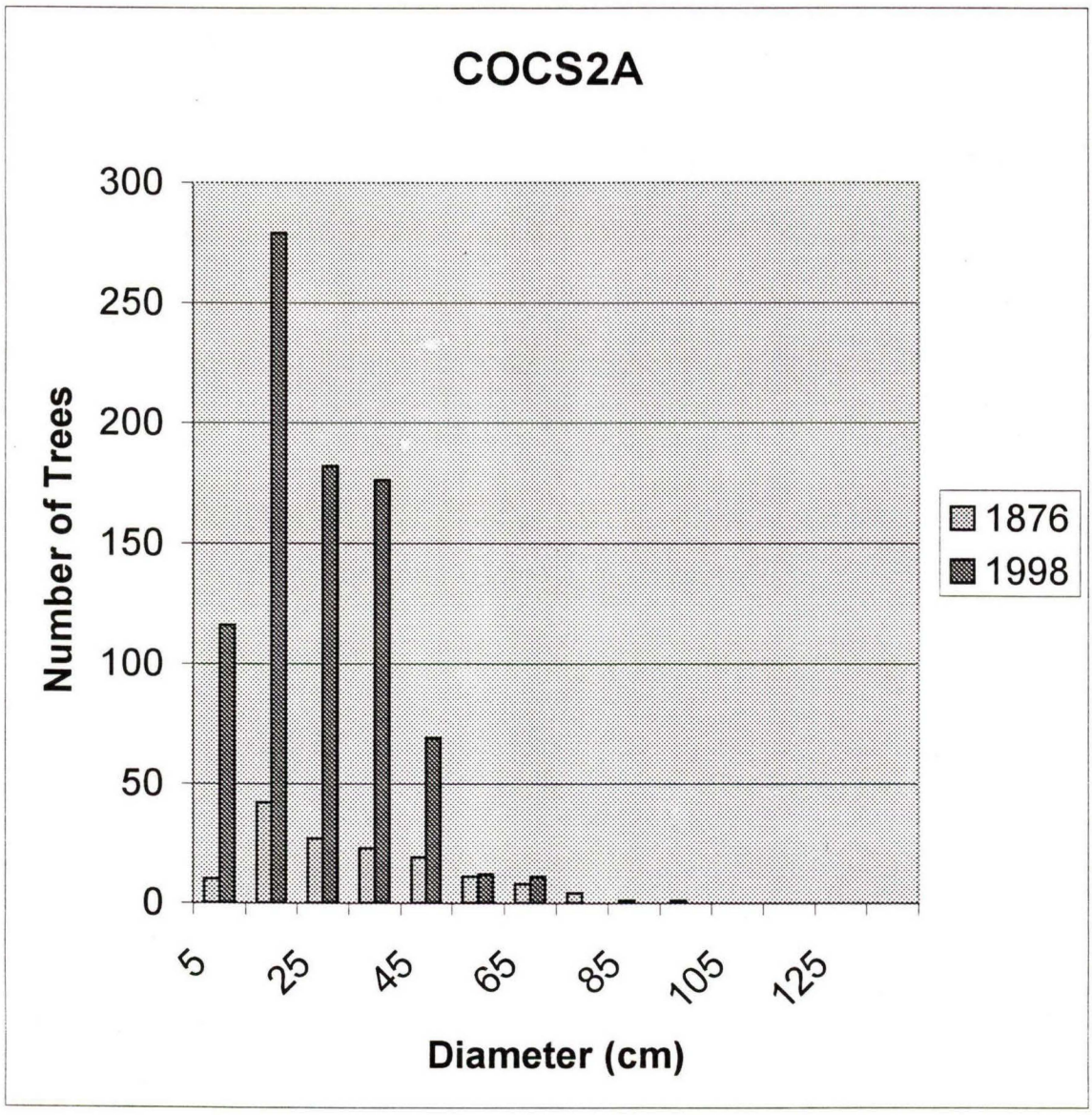
Charts of diameter distributions at time of fire exclusion (1876 - 1890) and remeasurement date (1997 - 1999)

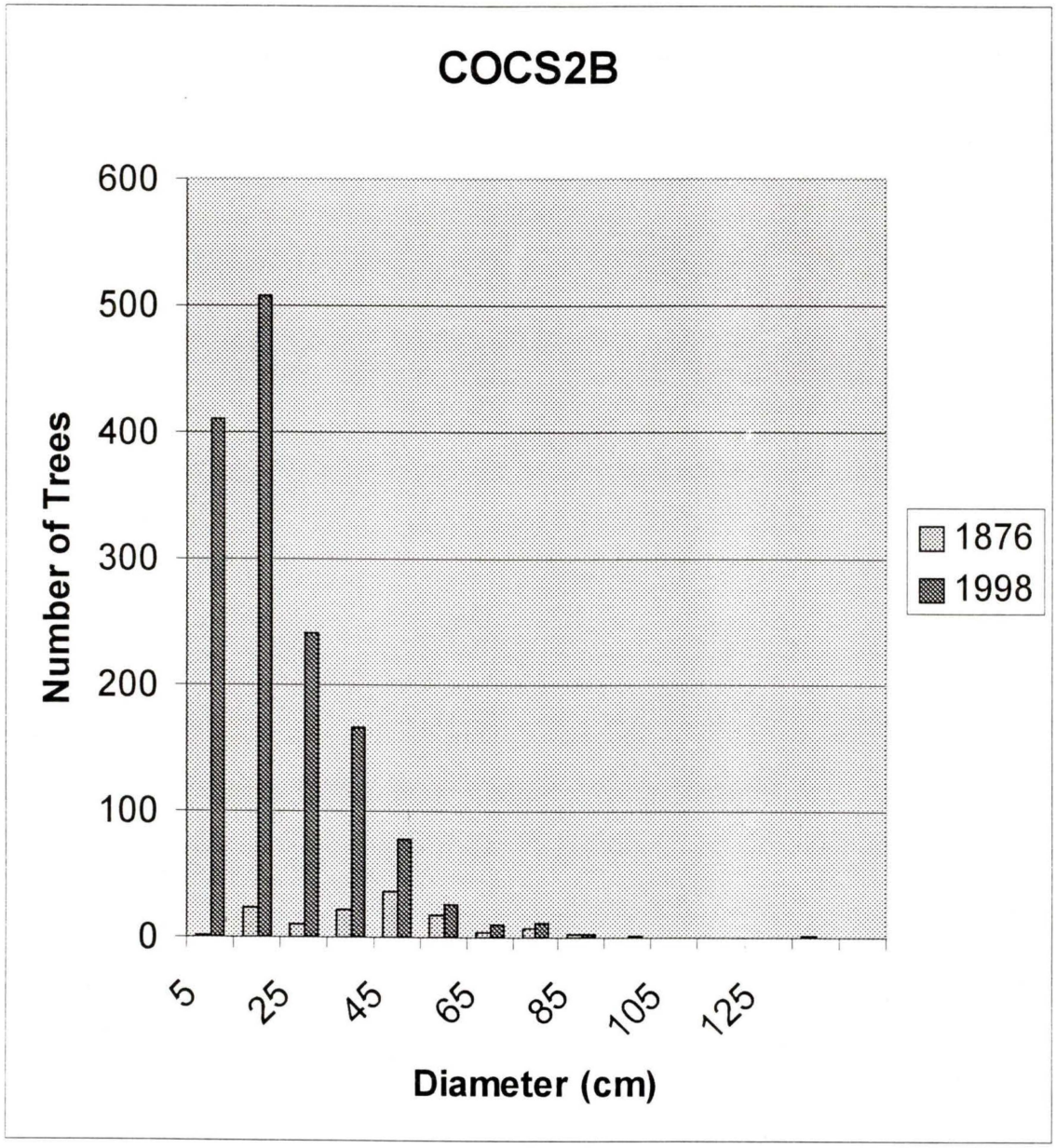

CIBS1A
800
700
600
500
400
300
200
100
0
Number of Trees
5
25
45
65
85
105
125
Diameter (cm)
1890
1998

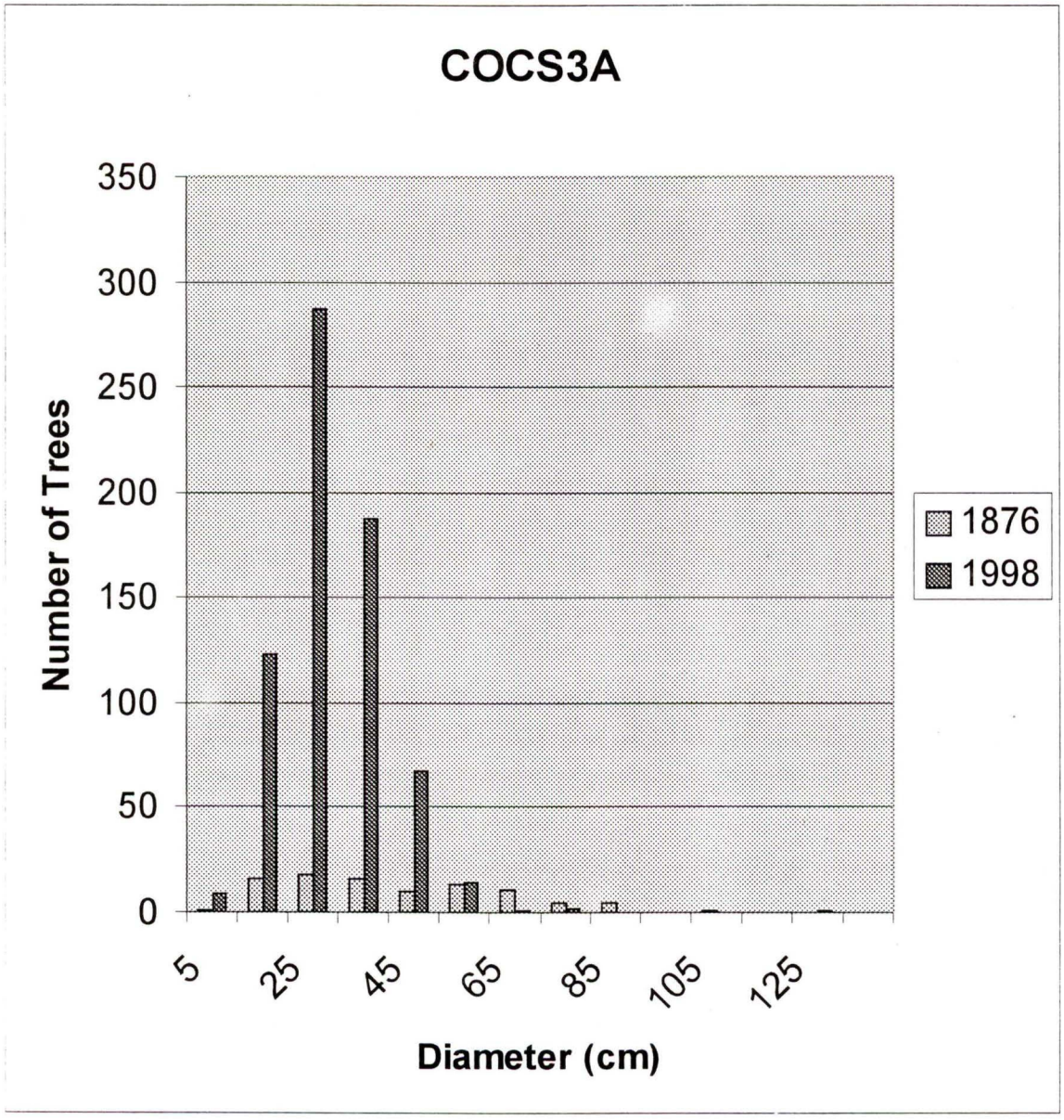

CIBS2A
250
200
150
100
50
0
Number of Trees
5
25
45
65
85
105
125
Diameter (cm)
1890
1998

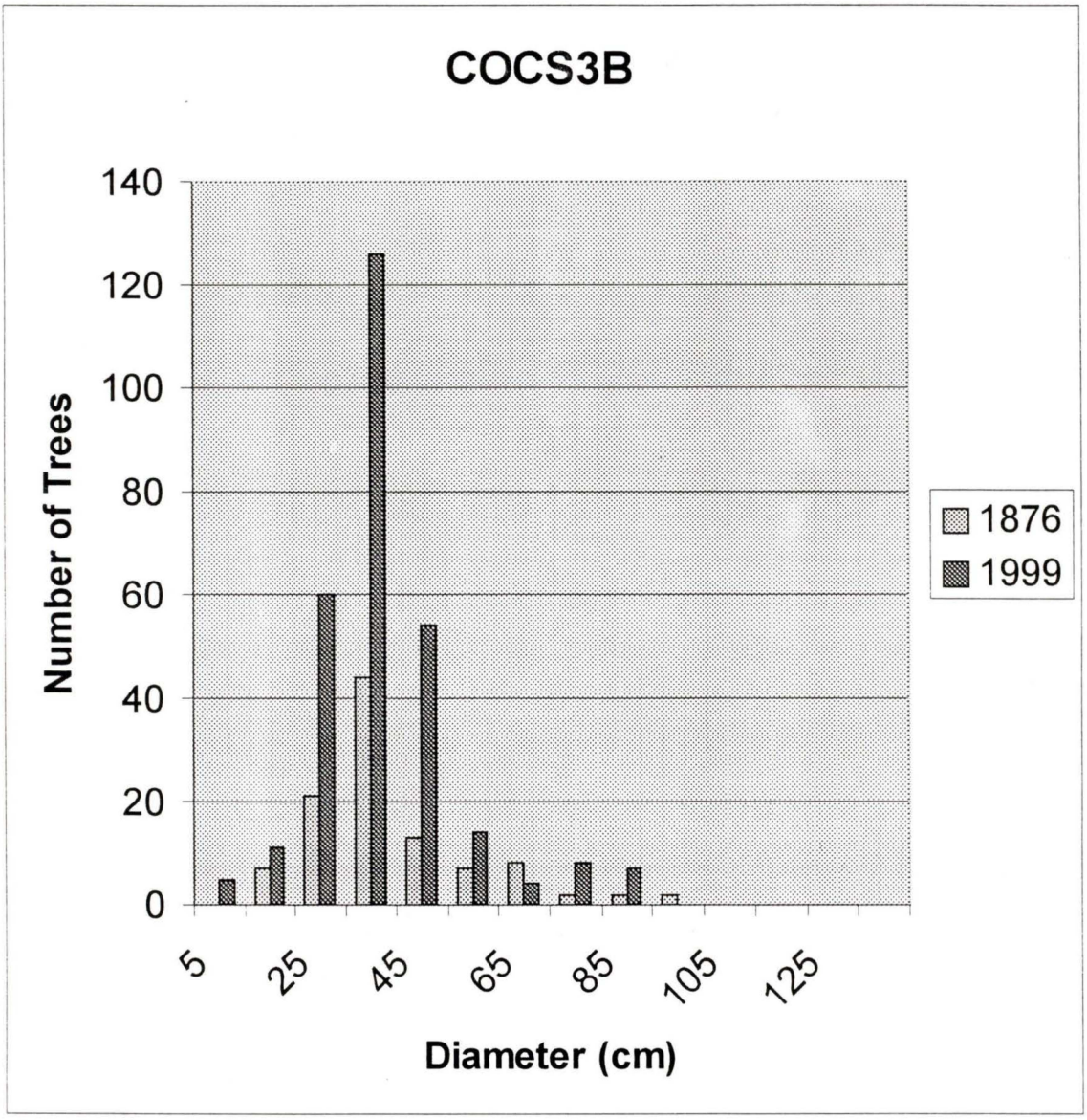

COCS1A
350
300
250
200
150
100
50
0
Number of Trees
5
25
45
65
85
105
125
Diameter (cm)
1876
1997

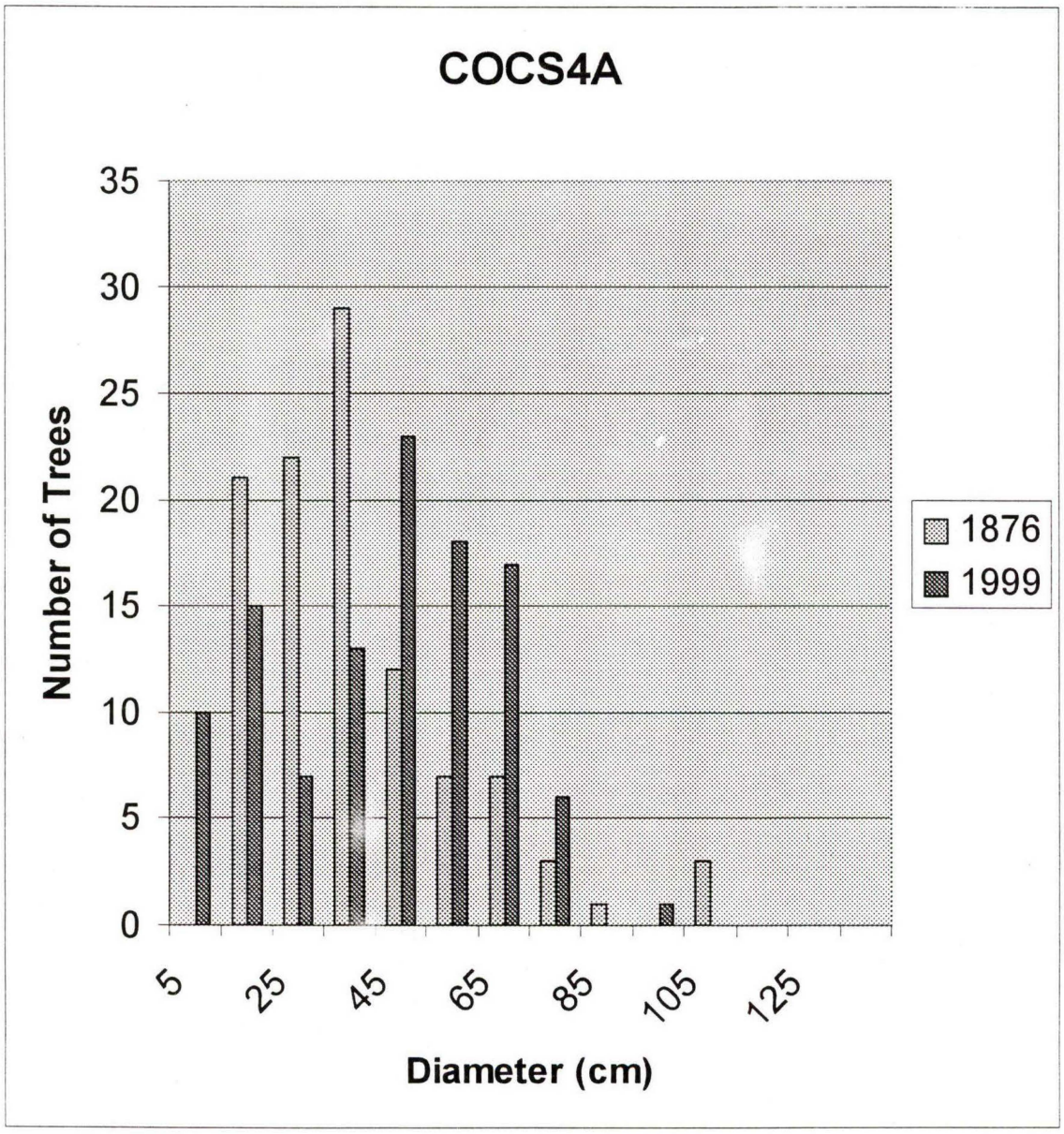

COCS1B
1400
1200
1000
800
600
400
200
0
Number of Trees
5
25
45
65
85
105
125
Diameter (cm)
1876
1998

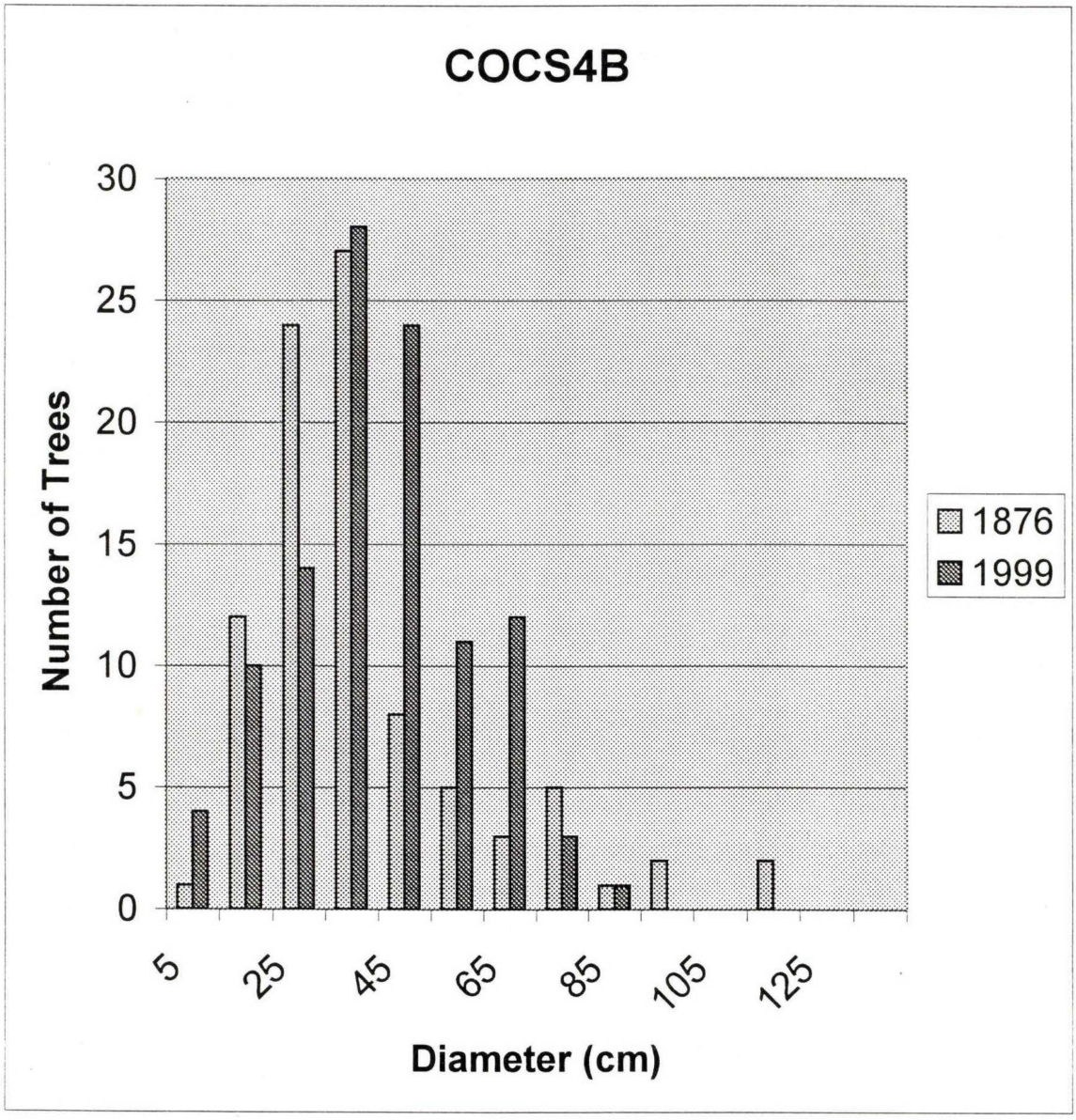

COCS2A
300
250
200
150
100
50
0
Number of Trees
5
25
45
65
85
105
125
Diameter (cm)
1876
1998

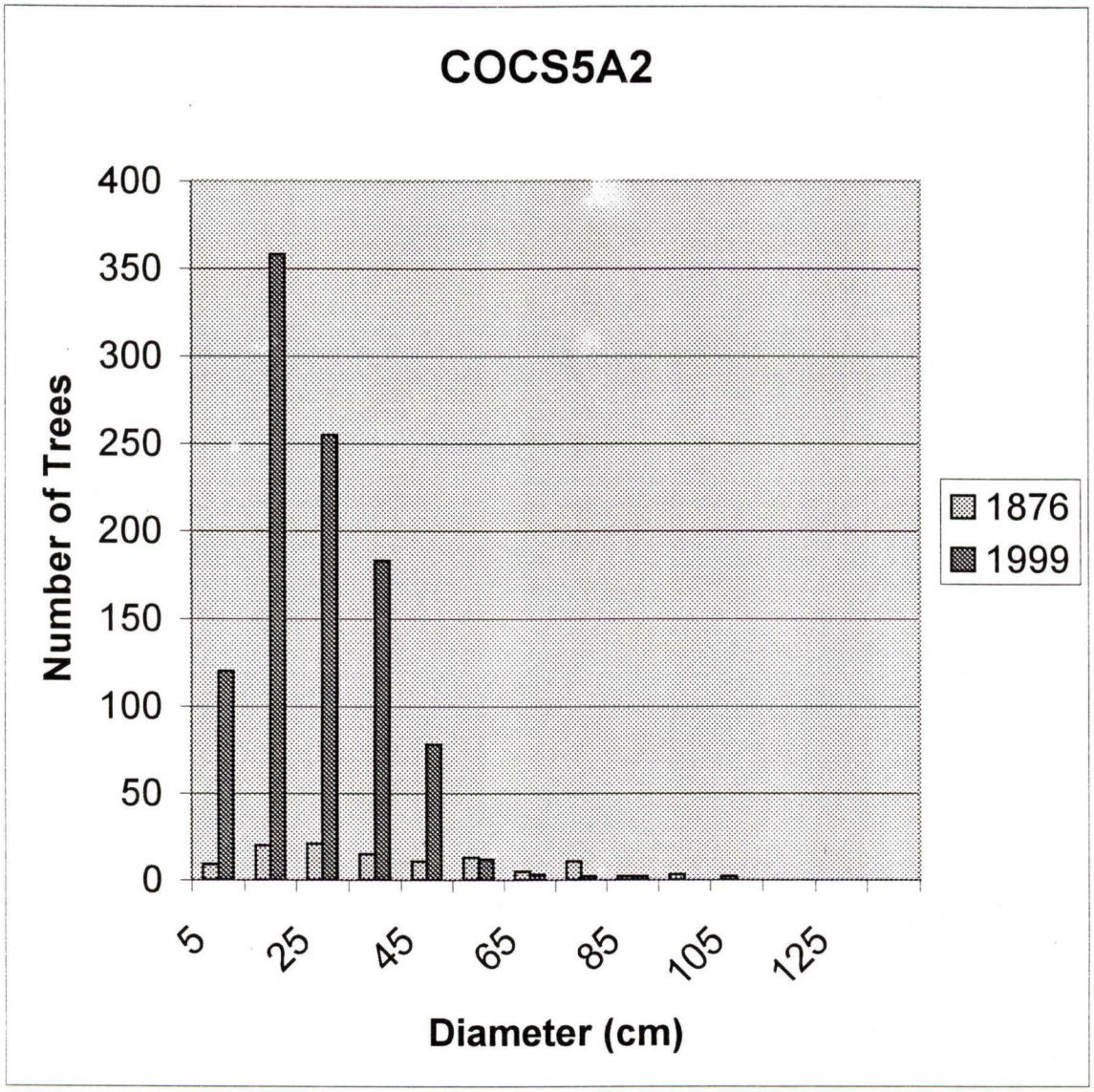

COCS2B
600
500
400
300
200
100
0
Number of Trees
5
25
45
65
85
105
125
Diameter (cm)
1876
1998

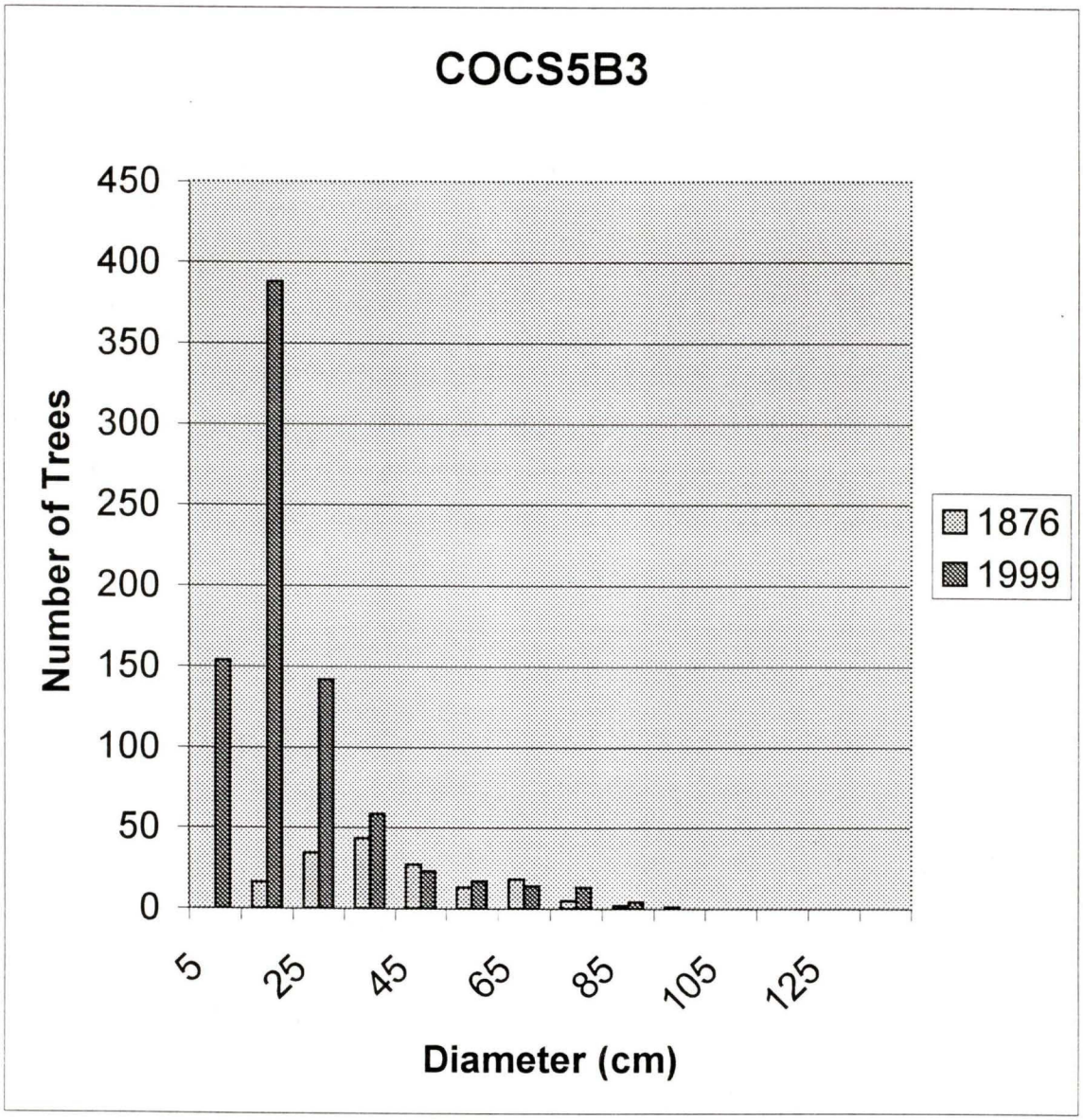

COCS3A
350
300
250
200
150
100
50
0
Number of Trees
5
25
45
65
85
105
125
Diameter (cm)
1876
1998

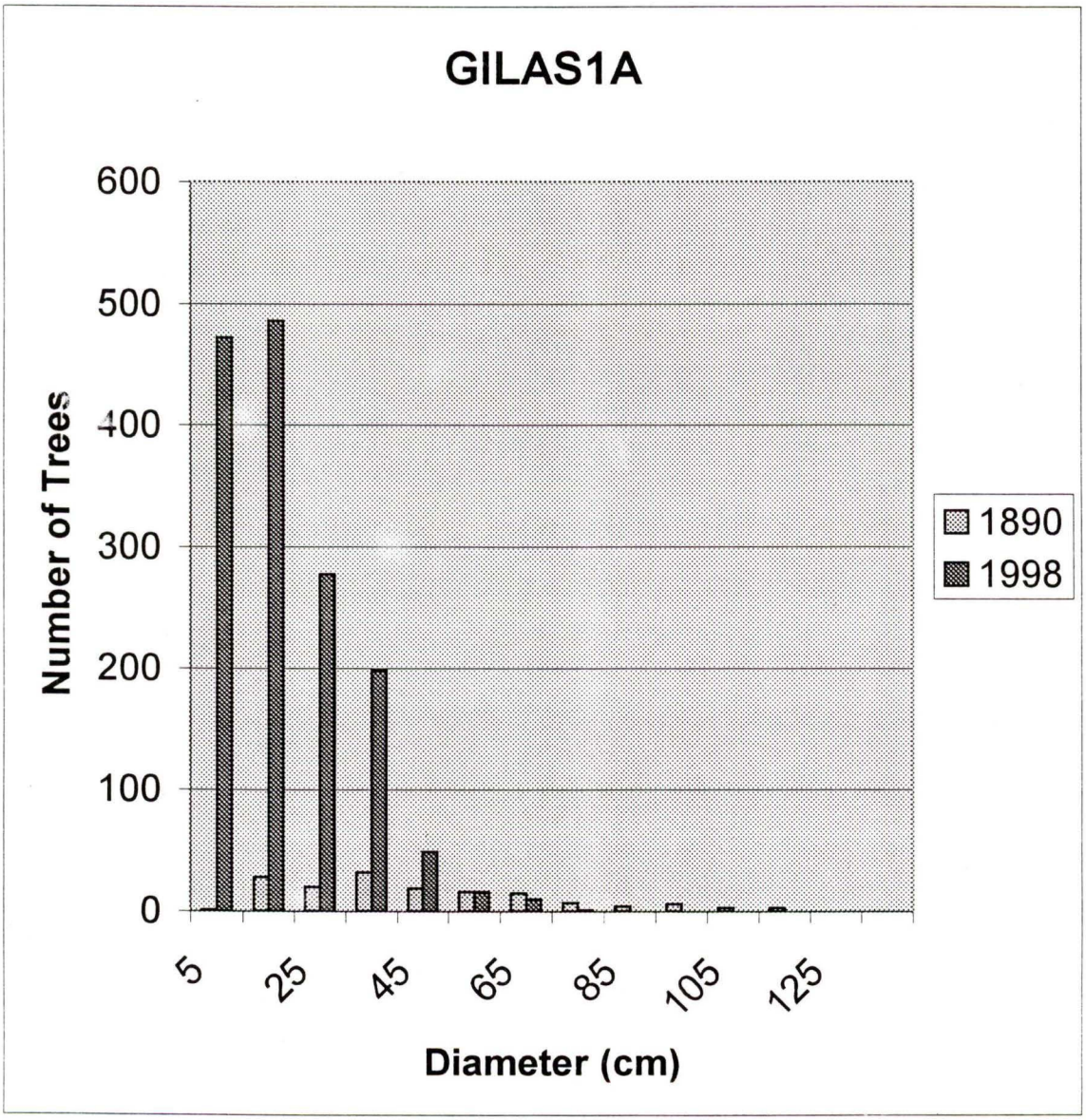

COCS3B
140
120
100
80
60
40
20
0
Number of Trees
5
25
45
65
85
105
125
Diameter (cm)
1876
1999

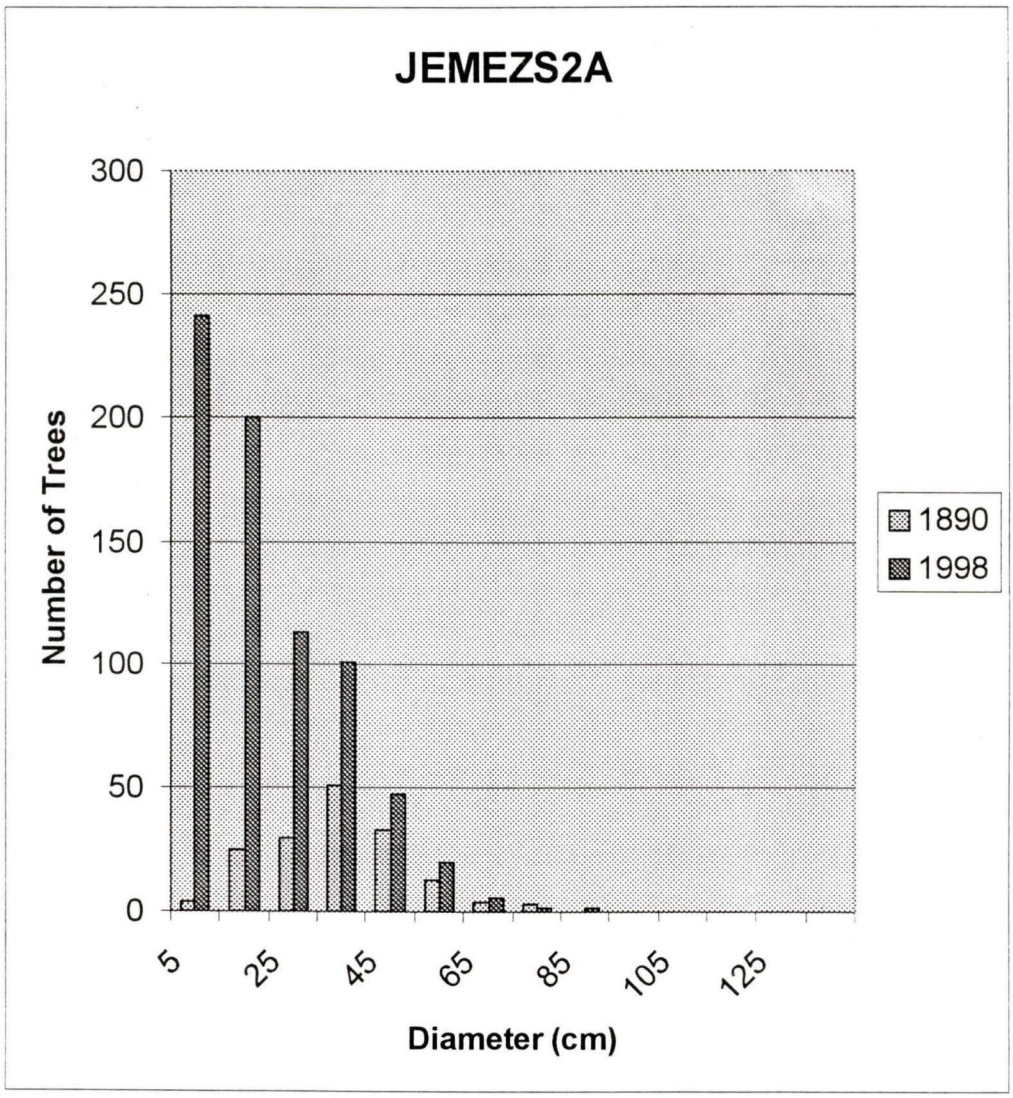

COCS4A
Number of Trees
35
30
25
20
15
10
5
0
5
25
45
65
85
105
125
Diameter (cm)
1876
1999

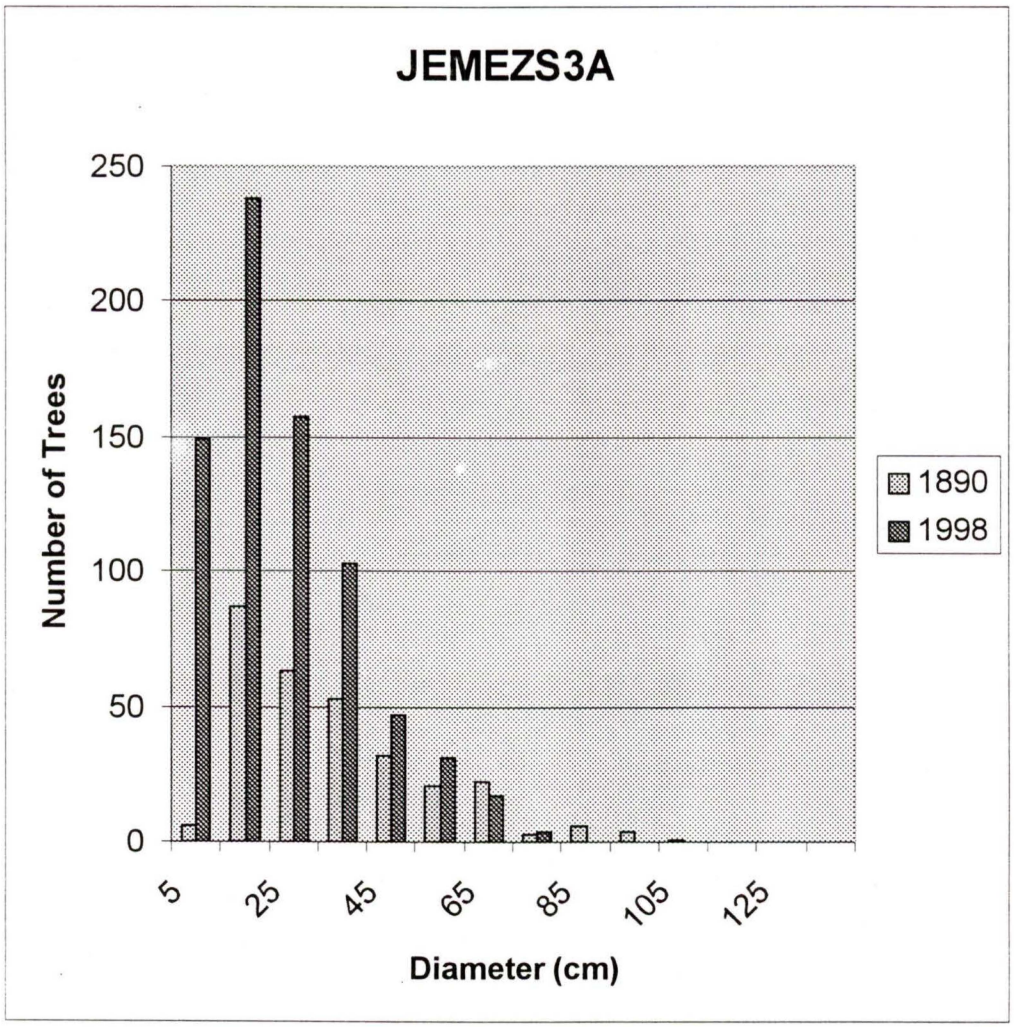

COCS4B
Number of Trees
30
25
20
15
10
5
0
5
25
45
65
85
105
125
Diameter (cm)
1876
1999


COCS5A2
400
350
300
250
200
150
100
50
0
Number of Trees
5
25
45
65
85
105
125
Diameter (cm)
1876
1999


COCS5B3
Number of Trees
450
400
350
300
250
200
150
100
50
0
5
25
45
65
85
105
125
Diameter (cm)
1876
1999


GILAS1A
600
500
400
300
200
100
0
Number of Trees
5
25
45
65
85
105
125
Diameter (cm)
1890
1998


JEMEZS2A
300
250
200
150
100
50
0
Number of Trees
5
25
45
65
85
105
125
Diameter (cm)
1890
1998


JEMEZS3A
250
200
150
100
50
0
Number of Trees
5
25
45
65
85
105
125
Diameter (cm)
1890
1998

Appendix VII:

Supplemental report: Woolsey plots in relation to climatic and floristic variation in southwestern ponderosa pine forests. By W. Moir. USFS, Rocky Mountain Research Station, Flagstaff, AZ

Woolsey plots in Relation to Climatic and Floristic Variation in Southwestern Ponderosa Pine Forests.

Supplemental Report Woolsey Project, August 3, 2000

W.H.Moir

1. Questions.

Are studies in forest structure and restoration conducted in Southwestern ponderosa pine/bunchgrass forests directly applicable to other ponderosa pine forests in the Southwest? How well do the Woolsey plots portray the range of climatic and floristic variations within Southwestern ponderosa pine forests?

2. Method used to address questions.

Results of studies conducted in pine/bunchgrass habitats can be extended to areas of similar habitats elsewhere in the Southwest, including the *Pinus ponderosa/Festuca arizonica, P. ponderosa/ Muhlenbergia virescens, P.ponderosa/Poa fendleriana,* and other habitat types (hts) where bunchgrasses are understory dominants (Muldavin et al 1990). We address the above questions using habitat type (ht) data gathered across New Mexico, Arizona and southern Colorado (Muldavin et al 1990), as well as within 7 Woolsey plots and plots sampled at weather stations within the Southwestern ponderosa pine region or near the ponderosa pine/woodland ecotone. Each weather station was visited to certify that present and previous locations (if the station was moved during the period of record) were within the indicated ht of the ponderosa pine region or adjoining woodland. All plot data were obtained by consistent habitat typing techniques (Pfister and Arno 1980). In particular, plots were located within stands at sites least disturbed by recent human activities. These were open yellow-pine sites or, in few instances, open blackjack pine sites whose oldest trees were over about 150 years old at breast height. By locating plots at such sites we mostly precluded early successional plant species appearing in the understory.

A total of 327 plots each containing at least 6 tree and/or understory variables were ordinated using non-metric scaling (Clarke 1993), as determined in DECODA by Peter Minchin. We employed the Bray-Curtis algorithm as the similarity measure between

plots, and we log-transformed the field data to increase the contribution of minor species to the similarity computation. Ordinations were performed from a total of 77 tree density and understory canopy coverage variables that characterize the hts across the region (USFS 1997).

3. The ordinations.

Figure 1 summarizes important diagnostic features of the Southwestern ponderosa pine region. Part A locates plots within 6 hts (upper left box) and 13 weather stations (lower right box). The ponderosa pine/bunchgrass plots are distributed by the plots of f (*Pinus ponderosa/Festuca arizonica* ht) and m (*Pinus ponderosa/Muhlenbergia virescens* ht). Plots of hts with evergreen oaks are plotted by h, a, and G. Plots of the *Pinus ponderosa/Quercus undulata* ht (wavyleaf oak is a hybrid between *Quercus grisea*, a winter evergreen oak and *Q.gambelii*, a winter deciduous oak), are shown by U.

Weather stations at Grand Canyon National Park (Gr), Mayhill (Ma), and Oracle (Or) are in woodlands near ponderosa pine stands. All remaining weather stations are within the ponderosa pine region. Stations at Los Alamos (Los) and Ruidoso (Ru) have wavyleaf oak (*Quercus* undulata) as an understory dominant. The station at Tres Piedras (Tp) has *Artemisia tridentata* as an understory dominant. The Fort Valley (Fv) weather station has both *Festuca arizonica* and *Muhlenbergia montana* as codominant understory bunchgrasses, but blue grama (*Bouteloua gracilis)* is present in minor amounts as an indicator of a warm-dry microclimate (USDA 1995). Both the Luna (Lu) and Chevelon (Ch) stations have blue grama (a mat-forming grass under most field conditions) as a dominant or codominant species. The station at McNary (Mc) is clearly within the *Pinus ponderosa/Muhlenbergia virescens* ht, with screwleaf muhly (*M. virescens*) an understory dominant bunchgrass. The weather station at Payson (Pa) has *Quercus emoryi* (Emory oak) as a tree codominant, and at Palisades (Pa) *Q. hypoleucoides* (silverleaf oak) is a tree codominant.

Figure 1B is an interpretation of the ordination in Fig. 1A. The climate characterized as High Sun Cold (HSC) (Moir 1997, USDA 1991) extends across the ponderosa pine/bunchgrass plots (f and m). It includes the Chevelon (Ch), Fort Valley (FV), and McNary (Mc) weather stations. The soil temperature regime of HSC is frigid (USDA 1991). The High Sun Mild (HSM) climate (Moir 1997, USDA 1991) is reflected by

vegetation and climatic data at the Oracle (Or), Payson (Pa), and Palisades (Pl) weather stations. The soil temperature regime of HSM is mesic (USDA 1991). The arrow from Or to Pl in Figure 1 suggests the well-known vegetation gradient of the Santa Catalina Mountain south-facing slopes (Whittaker and Niering 1965). The range of wavyleaf oak (U in Fig. 1B) includes the Los Alamos (Los), Luna (Lu), Ruidoso (Ru), and Mayhill (Ma) stations. The climatology of this oak may be similar to that of *Quercus turbinella* in Arizona and Utah (Neilson and Wullstein 1983, Neilson et al 1992). Similarly, we interpret this as a tension zone between cold and mild winters, responsive, in part, to the climatic flux of subcontinental air masses. This zone also coincides with the ordination plot distribution of the *Pinus ponderosa/Bouteloua gracilis* ht (not shown) and also with the distribution of blue grama itself (not shown). The zone is often referred to by Forest Service people as "fringe pine", and is characterized by ponderosa pine forests which include many species of the pinyon-juniper woodlands.

The Tres Piedras (Tp) and Tusayen (not shown) weather stations feature *Artemisia tridentata* in the understory, and reflect a Great Basin climate, described as Low Sum Cold (LSC) (Moir 1997, USDA 1991). The orientation of these weather stations superimposes upon the HSC/HSM sector of Fig. 1B and is poorly characterized in this ordination space limited to two dimensions.

Figure 1C locates the Woolsey and weather station plots within the climatic zones depicted in Fig. 1B. Six Woolsey plots are in ponderosa pine/bunchgrass hts in the HSC climate. Three of these plots in northern Arizona are in the *Pinus ponderosa/Festuca arizonica* ht. One at Fort Valley (FV1) and another at Sunset Crater National Park (not shown) are in *Pinus ponderosa/Festuca arizonica-Bouteloua gracilis* and *P. ponderosa/Muhlenbergia montana-Bouteloua gracilis* hts respectively. The sixth in the San Mateo Mountains, NM (Cib1) is in the *Pinus ponderosa/Muhlenbergia virescens* ht. This plot contains the deciduous gambel oak (*Quercus gambelii*). These plots do not significantly extend the range of studied ponderosa pine plots to other climates or forest structures , as posed in the questions above, but all seem to be variants of ponderosa pine/bunchgrass forests.

Two Woolsey plots, however, are very different. The Woolsey plot at Los Alamos, NM is within the tension zone between HSC and HSM climates. Additional structural and compositional features of this stand include the presence of species of woodland

affinity, such as junipers (especially *Juniperus monosperma*), pinyon pine (*Pinus edulis*), wavyleaf oak (5% cover in the plot), and skunkbush sumac (*Rhus aromatica* at 4% cover). The second Woolsey plot in the San Mateo Mountains (Cib2) differs from the other (Cib1) in that both Gray and wavyleaf oaks, which are evergreen and semi-evergreen respectively, occur (with combined cover of 1.4%) instead of gambel oak. We assigned this plot to the *Pinus ponderosa/Quercus grisea* ht (Pipo/Qugr in Fig 1A) within the HSM climate.

4. Conclusions.

The differences and similarities among the Woolsey plots are suggested by both floristics and climate data from the weather stations and by their proximity to one another in the ordination (Figs.1A and 1B). The DECODA ordination placed habitat type, Woolsey, and weather station plots in a Southwestern regional perspective. We suggested above that the pattern of plots in the 2-dimensional ordination space revealed contrasting and gradational climate patterns mainly from HSC to HSM. The HSC climate includes the ponderosa pine/bunchgrass hts. Only two Woolsey plots were ordinated outside the HSC sector. A fringe pine Woolsey plot at Los Alamos was ordinated within the tension climatic zone (HSC/HSM), and a pine/gray oak Woolsey plot in the San Mateo Mountains was within the HSM climate sector . However, as hinted in Figure 1C, there remains considerable climatic and floristic forest diversity in terms of habitat types in the Southwestern ponderosa pine region (e.g., Moir and Fletcher 1996) not represented by Woolsey plots.

5. Literature Cited

Clarke, K.R. 1993. Non-parametric multivariate analyses of changes in community structure. Australian J. Ecol. 18: 117-143.

Muldavin, E.; F. Ronco, Jr.; Earl F. Aldon. 1990. Consolidated stand tables and biodiversity data base for Southwestern forest habitat types. USDA Forest Service General Technical Report RM-190, 51 p + computer diskettes.

Neilson, R.P. and L.H. Wullstein. 1983. Biogeography of two southwest American oaks in relation to atmospheric dynamics. J. Biogeography 10: 275-297.

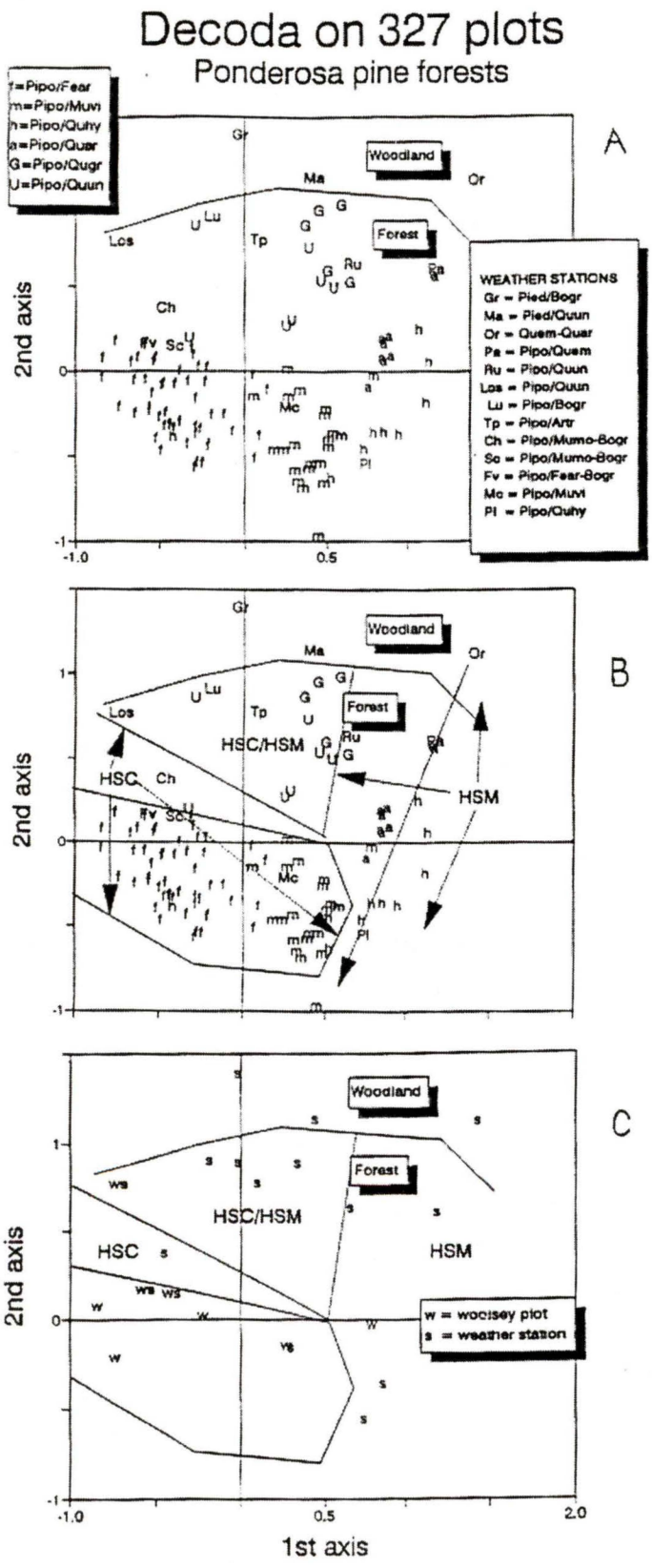
Neilson, R.P.; G.A. King; R.L. DeVelice; J.M. Lenihan. 1992. Regional and local vegetation patterns: the responses of vegetation diversity to subcontinental air masses. Pp 129-149 in: Hansen, A.J. and F. Di Castri (editors), Landscape boundaries, Springer-Verlag, NY.

Pfister, R.D. and S.F. Arno. 1980. Classifying forest habitat types based upon potential climax vegetation. Forest Science 26: 52-72.

USDA Forest Service. 1995. Terrestrial ecosystems survey of the Coconino National Forest. USDA Forest Service Southwestern Region, Albuquerque, NM, 405 p.

USDA Forest Service. 1997. Plant associations of Arizona and New Mexico, Edition 3, Volume 1: Forests. USDA Forest Service Southwestern Region, Albuquerque, NM, iv, 291 p.

Whittaker, R. H. and W.A. Niering. 1965. Vegetation of the Santa Catalina Mountains, Arizona: a gradient analysis of the south slope. Ecology 46: 429-452.


Decoda on 327 plots
Ponderosa pine forests
f=Pipo/Fear
m=Pipo/Muvi
h=Pipo/Quhy
a=Pipo/Quar
G=Pipo/Qugr
U=Pipo/Quun
A
B
C
Woodland
Forest
HSC
HSC/HSM
HSM
2nd axis
1st axis
WEATHER STATIONS
Gr = Pied/Bogr
Ma = Pied/Quun
Or = Quem-Quar
Pe = Pipo/Quem
Ru = Pipo/Quun
Los = Pipo/Quun
Lu = Pipo/Bogr
Tp = Pipo/Artr
Ch = Pipo/Mumo-Bogr
Sc = Pipo/Mumo-Bogr
Fv = Pipo/Fear-Bogr
Mc = Pipo/Muvi
Pl = Pipo/Quhy
w = woolsey plot
s = weather station